Characterization of Sprays for a Particle-Coating Liquid

by

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Dissertation submitted in partial fulfillment of

The requirements for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

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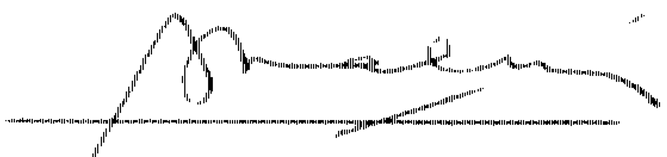
Approved by,



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September 2011

CERTIFICATION OF ORIGINALITY

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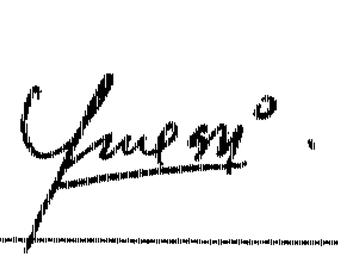

MUHAMMAD YUSRI BIN MOHAMAD YUSOFF

ABSTRACT

Coating of fertilizer nowadays plays important role in agriculture industry. Through this technology, plantation growth due to supply of nutrients from fertilizer granules could be controlled accordingly. Its application is wide, from supplying nutrient for a long period for crops such as maize to controlling even growth of soccer field grass. Besides that, the coating also mitigates the amount of nitrous oxide released by fertilizer. This is paramount as it contributes to green house effect. The coating of fertilizer is able to control the release of nutrient due to its porous characteristic. Thickness and evenness of the coating liquid are important as they affect the performance of a coated fertilizer. In order to plan for the coating process, characterization of sprays for this coating liquid has to be studied. As such, it is the objective of this project to determine the breakup structure of spray droplet, spray droplet size, spray droplet velocity profile, spray angle, droplet concentration and spray penetration. There are several factors affecting the aforementioned parameters. Equipments such as Phase Doppler Analyzer (PDA), Laser Diffraction Analyzer (LDA) and high speed digital camera are needed to experiment the factors. Through the use of LDA/PDA system, spray droplet size and droplet velocity in vertical and horizontal directions could be measured. On the other hand the camera would enable determination of spray angle and spray droplet breakup structure. Two types of fluid were used throughout the project and they were liquid modified starch (the particle coating liquid) and water. The results of both liquids were compared to determine the effects of liquids properties on the spray characteristics. It was found that water generally has smaller spray droplet size compared to liquid modified starch. Besides that, water was bigger magnitude in vertical velocity than the particle coating liquid in contrast to horizontal velocity as liquid modified starch was bigger in magnitude. As for the spray angle, water spray produces larger spray width than liquid modified starch.

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ABBREVIATIONS

LDA	Laser Doppler Anemometry
PDA	Phase Doppler Anemometry
Re	Reynolds Number
We	Weber Number
SMD	Sauter Mean Diameter

CHAPTER 1

INTRODUCTION

1.1 Background

Spray is basically a dynamic collection of drops dispersed in gas. The main functions of spray are to distribute spraying liquid over a cross-section and to generate liquid surface. These are achieved by the manipulation of droplet size, droplet velocity and droplet breakup structure. Device to form a spray is called spray nozzle. The common methods of using nozzle to form spray are pressure atomization and two fluids atomization. In pressure atomization, spray fluid is pressurized through a nozzle. As for the two fluids atomization, air is pressurized through nozzle while spray liquid enters nozzle as result of pressure difference between fluid's container and air flow. Spray or fluid's droplet generation could be divided into two phases which are primary and secondary atomization. These phases of atomization influenced the size of droplets could be achieved. Primary atomization is where droplets are formed from fluids coming out of nozzle in sheets and ligament form. Secondary atomization is what takes place after primary atomization where the droplets break to even smaller droplets.

Application of spray characteristic is wide and important as it helps material of spray to be used most efficiently. Its application could be seen in automotive industry where fuel injector in an engine to produce fuel spray and manufacturing industry where spray painting is utilized. Apart from that spray technology is also used to do coating on fertilizer granules in agricultural industry. To spray coat fertilizer granules, fluidized bed coating system is normally used. This technology is very important in coating the fertilizer granules as the coating plays important role to the performance of the fertilizer.

The coating enables the control over the release rate of the nutrient to the soil which could elongate its life span. Uncoated fertilizer will react with water to release the nutrient this reaction would release high amount of nutrient. This way, excessive amount of nutrient is wasted due to rain and improper watering. With the use of coating, nutrient release would be only due to reaction with heat of the soil and this release rate is relatively lesser. Hence, only required amount of nutrient by the plantation would be released and wasted nutrient significantly reduced. Besides that, the coating also

mitigates nitrous oxide emission which contributes to the green house effect. The coating thickness on the fertilizer important as it determines the release rate of the nutrient to the soil. The thicker the coating, the fertilizer has less nutrient release rate and the longer lifespan. Hence the spray coating technology is paramount to produce coating according to targeted amount thickness.

1.2 Problem Statement

A coating liquid which called liquid modified starch has been developed to coat fertilizer granules. The liquid film will coat fertilizer granules using a fluidized bed coating system. The coating liquid needs to be sprayed on fertilizer granules and the spray must be able to coat the granules evenly and according to desired coating thickness. Coating's evenness and thickness are very important as they have significant influence on the fertilizer performance. Through coating thickness, the fertilizer life span and release rate of nutrient to the soil could be controlled. If the thickness on the coating on the fertilizer is different than the designated value, then the desired life span and release rate of the fertilizer could not be achieved. As for the evenness of the coating on the granules, it is very crucial as most of fertilizer granules in irregular shape instead of ideal sphere. There might be an uncoated or less coated area on the granules. This exposed area would permit reaction of fertilizer with air or water producing nitrous oxide. The nitrous oxide gas emission needs to be mitigated as they contribute significantly to green house effect. Thus, having a proper design of the fluidized bed coating system is vital. As such, spray and droplet characteristics of this liquid is required in order to properly design the coating system. Therefore a study of spray characteristics of the liquid modified starch is required.

1.3 Objectives and Scope of Study

The objective of this project is to characterize the basic properties of sprays and droplets of coating liquid for the fertilizer granules under different conditions. The basic properties that need to be determined are the breakup structure of spray droplet, spray droplet size, spray droplet velocity profile, spray angle, droplet concentration and spray penetration.

The spray droplet size is the diameter of the liquid is spherical mass. In a particular spray, spray droplets comes in various sizes. The relation between spray droplet size and spray fluid pressure is determined by varying the pressure at a set of values. Thus diameters of those droplets at a few sets of pressure need to be measured and this could be done by using Phase Doppler Anemometry (PDA). After that, a mean and characteristic diameters are calculated from those measured diameters to properly describe droplet size distribution of a given spray.

Spray droplet velocity profile is basically the droplets' velocity in both vertical and horizontal direction with respect to spray flow which is downwards. The velocity profile could determine the penetration distance or in laymen terms, how far could the spray reach. The effect of spray fluid pressure towards the spray droplet velocity is investigated by varying the pressure exerted. The Laser Doppler Anemometry (LDA) is used to measure the droplet velocity in both horizontal and vertical direction. Average velocity is used to represent a given spray droplet velocity profile.

A spray angle is the measurement of width of spray coming out of nozzle. Spray angle influence the area that a spray could cover. Factors that affects spray angle are the fluid's flow pressure and the type of nozzle used. To measure the spray angle, a high speed camera is used to capture images of spray. From those images, spray angle is measured. High speed camera is also used to investigate the droplet breakup structure of a spray. Droplet breakup structure shows how droplets are formed after spray liquid pass through a nozzle.

Physical properties of spray liquid such as viscosity and surface tension have effects on spray properties. As such, the spray liquid used for this project which is liquid modified starch is compared against those spray properties of water. By comparing the two fluids, the effects of viscosity as well as surface tension on droplet size, velocity profile, spray angle and breakup structure could be determined.

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 Liquid Modified Starch

Starch is basically a carbohydrate with a plenty of glucose units joined by glycosidic bonds. It comes from various plant sources such as rice, potatoes, corn, wheat and cassava. Pure starch is white in color and only two types of molecule are present inside it. These molecules types are linear and helical amylase and the branched amylopectin. The composition of a starch usually comes in with 25% of the former molecule type while the latter is 75% (Brown, 2005). Starch modification, through the use of nano composite such as nanoclay, alter the physical and chemical characteristic of pure starch (Nik Omar, 2011). Through this modification, starch functions could be improved and tailored to specific applications. Starch could be modified to be a thickener, colloidal stabilizer, gelling agent, bulking agent and water retention agent at food processing condition of high temperature, high shear, low pH and even cooling. Besides that, starch is also modified to be a fertilizer's coating in agricultural industry.

2.2 Fertilizer granules coating

The purpose of coating on fertilizer granule is to control the release rate of nutrient from the urea to the crop field. The control was enabled by the properties of the coating of heat resistance, porosity and low solubility rate in water (Nik Omar, 2011). Uncoated urea releases nutrient to the plantation soil through the heat from the soil and dissolving in water via crop watering system and rain. Rain is a natural cause that could not be controlled and makes uncoated fertilizer granules release huge amount nutrients wastefully whenever it rains on the crop field. However, with the help of polymer coating on fertilizer granules, the urea solubility rate in water significantly lowered and the urea is tailored to release more nutrients due to heat from the soil. Thus, nutrients could be supplied according to the crops requirement and waste of nutrients extremely reduced. As the result, the fertilizer granules could last longer. Besides that, the coating mitigates the

amount of nitrous oxide released by the fertilizer. This is paramount as nitrous oxide contributes tremendously to green house effect.

Currently, starch polymer becomes an alternative to synthetic polymer which is conventionally used to coat fertilizer granules (Nik Omar, 2011). This is due to the society's concerns for environmental issues such as biodegradability and non-toxicity. In addition to that, the cost is also one of the factors considered in using starch polymer as it is cheaper compared to synthetic polymer. However, pure starch polymer is poor in terms of mechanical properties needed to coat fertilizer granules such as water solubility resistance. Hence, starch modifier like nanoclay is used to tailor the polymer to serve its function as coating properly.

In order for the coating to serve its function properly on the fertilizer granules, the coating has to encapsulate the fertilizer granules (Nik Omar, 2011). In addition to that, the spraying system used to perform the coating on the fertilizer granules should produce a spray with high area of coverage to coat hundreds of small granules simultaneously. The spray should also have large spray angle and velocity profile which has a lot of spray droplets going in both horizontal and vertical flow. Apart from that, the thickness of coating on fertilizer granules have to be controlled as it determines the performance of the fertilizer. The thicker the coating, the slower nutrients release rate becomes. To control the thickness, the coating system has to be able to produce spray droplet size range of 30 to 60 micron meter in diameter. This range of spray size enables the fertilizer to be coated to targeted amount of thickness to comply with the requirement of a particular type of crops.

2.3 Water

Water is a fluid that has abundant resources as approximately 71 percent of earth surface covered by oceans, not to mention the massive web of rivers on lands running down back to oceans (CIA, 2011). Most of all living creatures on earth or deep in the oceans depend on water to live. This shows how important water is to the world. Water usually found containing various minerals and other impurities. However pure water which is colorless and odorless only composed of two hydrogen atoms and an oxygen atom, forming H_2O. Water could exist in the phase of solid, liquid as well as fluid. The

phase of water could be present majorly depends on the water temperature and other factors such as impurities present in water like salt for instance. Water is also known as universal solvent as it could dissolves more substances compared to any other solvents. Apart from that, unless there are impurities present, pure water has pH of a neutral.

2.4 Atomization

Atomization could be defined as the process of generating spray droplet (Lefebvre, 1989). To generate this spray droplet, a device called as nozzle is used. Figure 2.1 shows an example of a nozzle forming a spray.

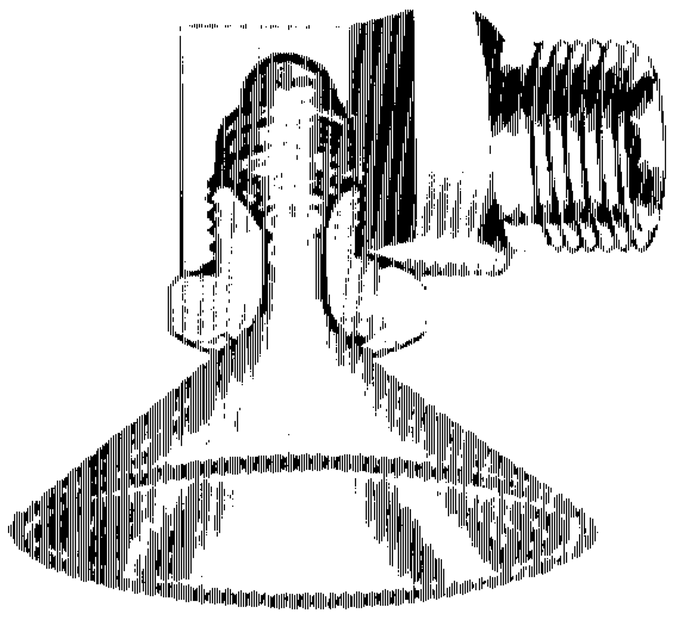

Figure 2.1: Example of a nozzle forming spray droplet (Schick, 2009).

Atomization process takes place as liquid is being forced through a nozzle. As the result, the liquid emerges as sheet formation which later formed to small ligaments due to the potential energy of it. These ligaments then break up further to form droplets. Figure 2.2 shows the changes in structures of a liquid passing through a nozzle.

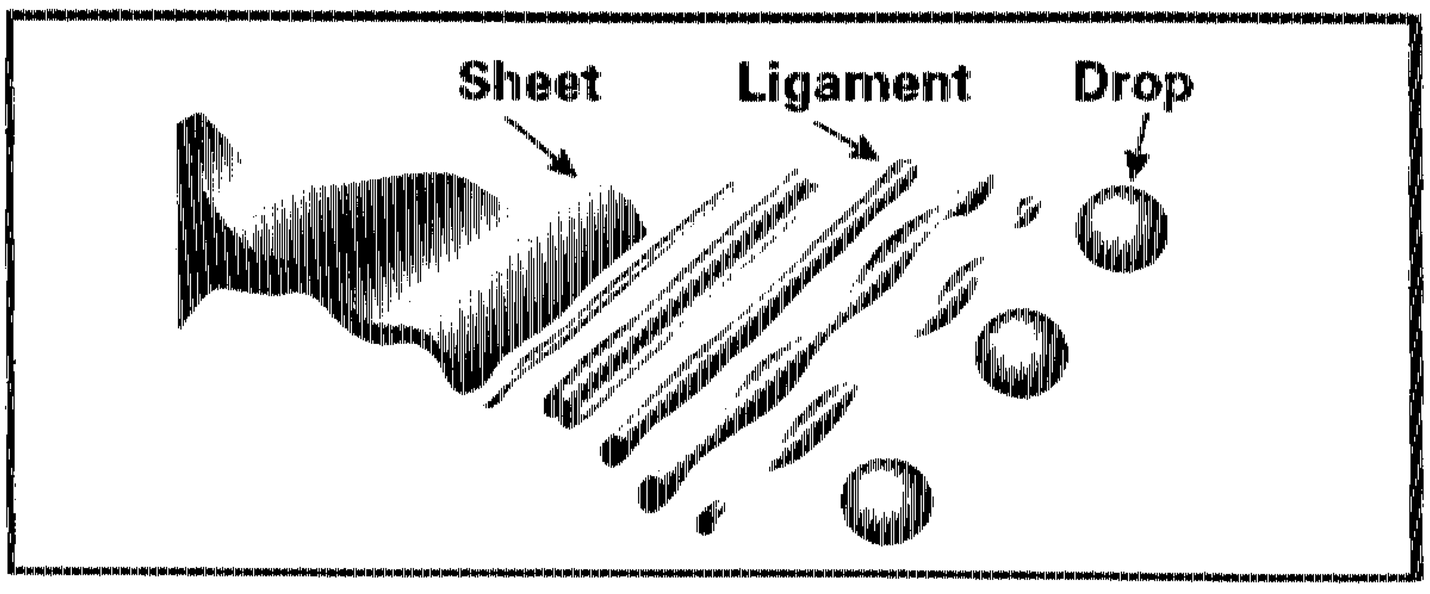

Figure 2.2: Atomization process of a liquid (Schick, 2009).

The most common atomization processes are pressure atomization and two fluids atomization. In pressure atomization, spray fluid is pressurized by utilizing pumping system. The pumping system enables fluid to flow to spraying gun where nozzle is attached. As for the two fluids atomization, two fluids are used to create spray they are air and spray fluid. Air is pressurized through nozzle while spray liquid enters nozzle as the result of pressure difference between fluid's container and air flow. This atomization process produces smaller spray droplets as compared to pressure atomization.

Pattern of spray or atomization is majorly influenced by the type of nozzle used to generate the spray (Schick, 2009). There are four basic types of nozzle used to generate spray and they are full cone nozzle, hollow cone nozzle, flat spray nozzle and air assisted nozzle. Each of these nozzles has distinct range of spray angle and spray pattern produced. Hollow cone nozzle could produce largest spray angle with the range of 100° - 180° followed by full cone nozzle with range of 15° - 125° and lastly flat spray nozzle with range of 25° - 65°. While for the air assisted nozzle, it is actually similar to the other three types in term of spray pattern and spray angle range. However, it is different from the others as it utilize the pressure of both spray liquid and air instead of relying only on spray liquid's pressure. Due to this, the nozzle would be able to produce spray with droplet size less than 100 micron. So, air assisted nozzle may have the same spray pattern and spray angle range as any of the other three but able to produce smaller droplet. Figures 2.3, 2.4, 2.5 and 2.6 show the spray pattern produced by each types of nozzle.

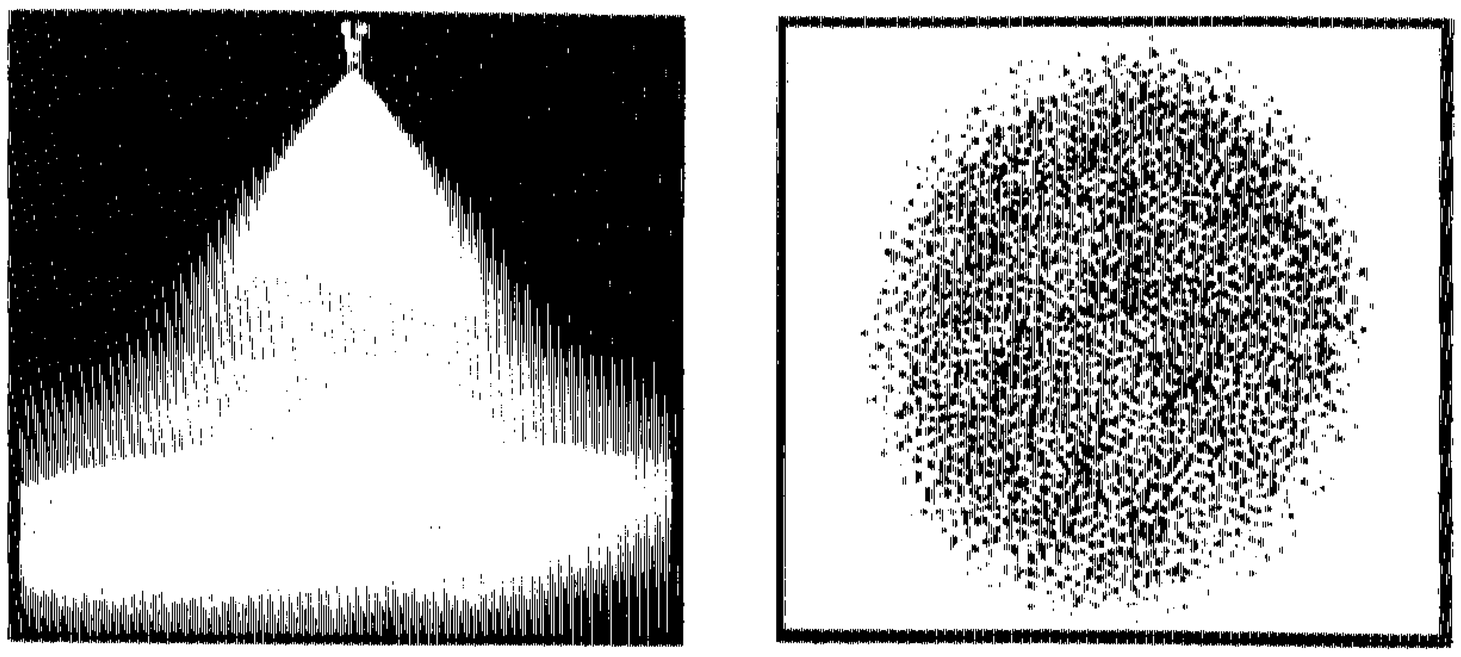

Figure 2.3: Spray pattern of full cone nozzle (Schick, 2009).

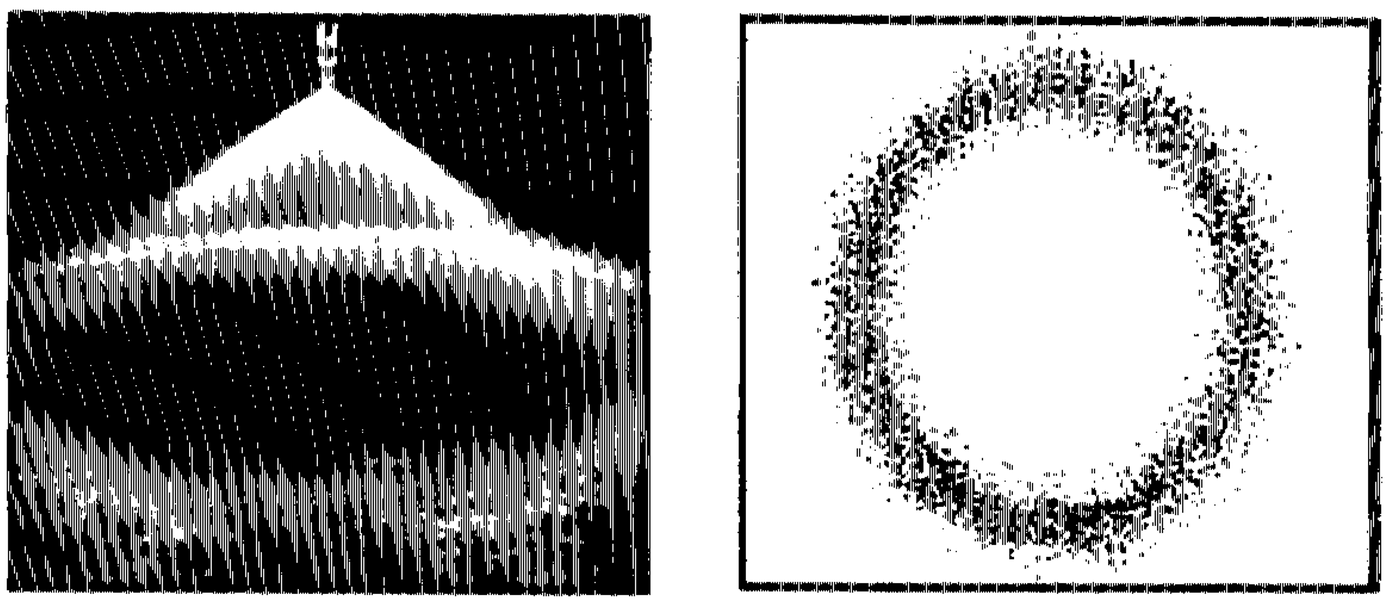

Figure 2.4: Spray pattern of hollow cone nozzle (Schick, 2009).

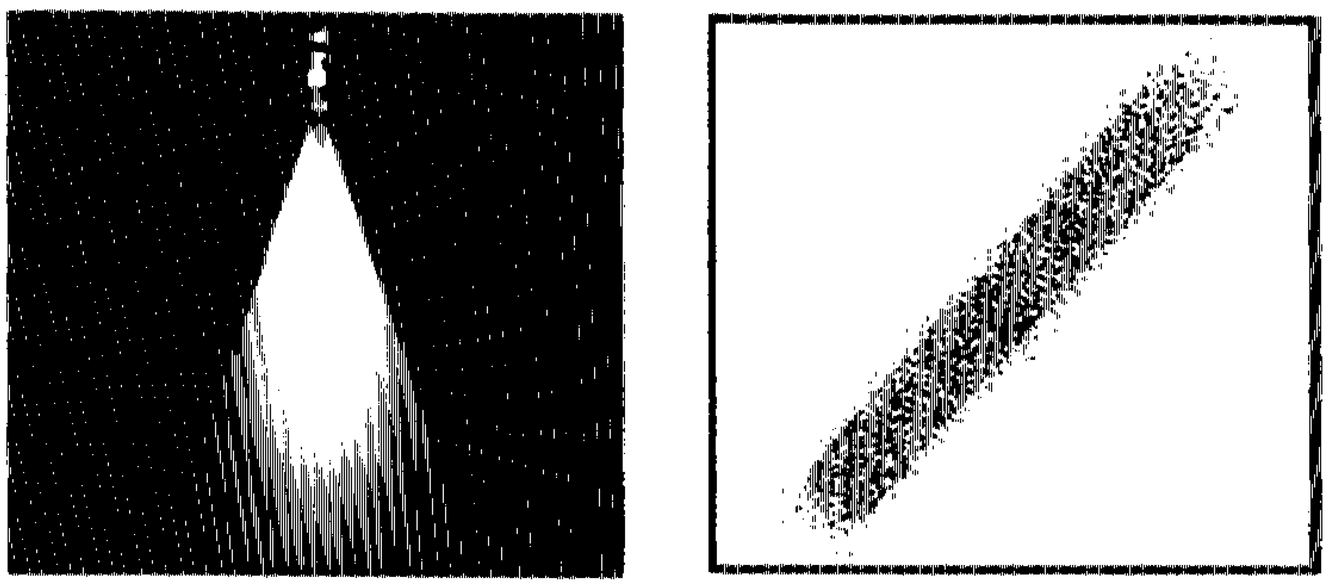

Figure 2.5: Spray pattern of flat spray nozzle (Schick, 2009).

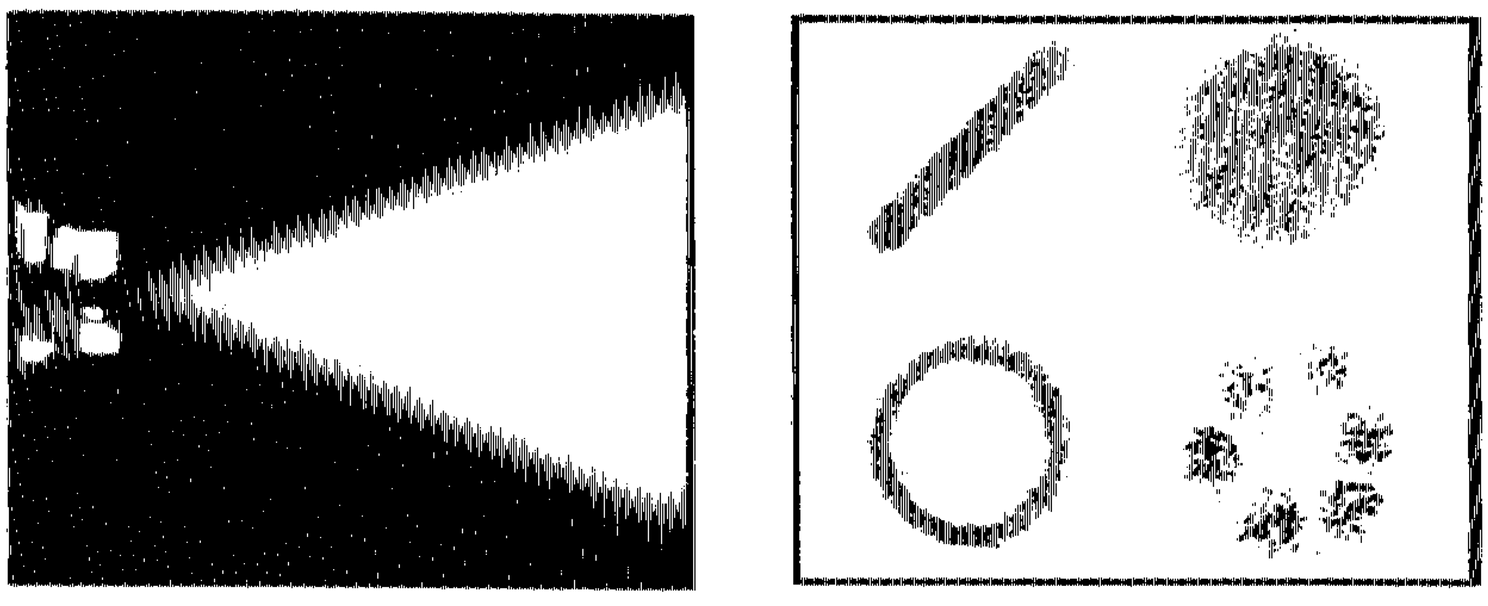

Figure 2.6: Spray pattern air assisted nozzle (Schick, 2009).

2.5 Droplet Breakup Structure

Droplet breakup is a phenomenon where droplets which were formed from liquid ligament, breakup further to form even smaller droplet. This phenomenon is also called secondary atomization. It is affected by viscosity, inertia and surface tension of the fluid and dimensionless parameters describing relationship of those fluid properties- Weber number and Rayleigh number. Droplet breakup structure only occurs when Weber

number of the spray exceed the critical value of 10 (Azzopardi, 2000). Having said that, all the droplets formed by primary atomization would experience secondary atomization only if the Weber number exceeds value of 14. Generally there are four distinct mode of breakup according to (Krzeczkowski, 1980). The first one is bag break up type. It is characterized by hollow bag-shaped film and a ring torus and occurs immediately above critical Weber number. Second type is bag jet breakup, characterized by the additional stamen in the middle of the bag. As for transition type, there is initial bag breakup but it transformed into disintegration of the bag film. While for shear or ligament type, it is characterized by the stripping of the surface layer. This type occurs at higher Weber number. Figure 2.7 shows the types of droplet breakup modes.

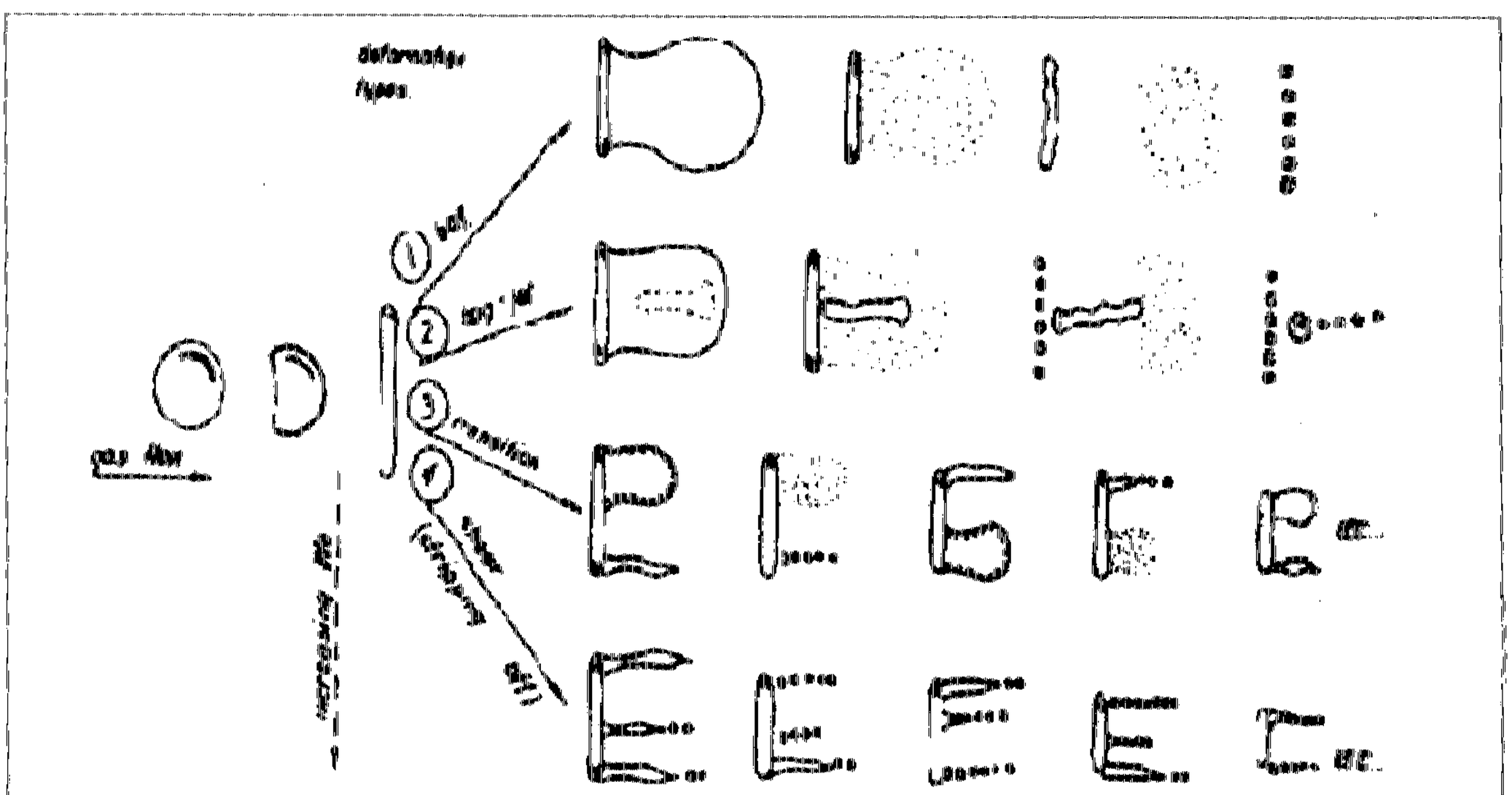

Figure 2.7: Illustration of four types of droplet breakup mode (Krzeczkowski, 1980).

2.6 Droplet Size of Sprays

Droplet size of sprays is the most important characteristic of sprays as it reflects the degree of atomization of the liquid. There are generally five classification of spray droplet size and they are ultra-fine atomization, fine atomization, semi-fine atomization, semi-coarse atomization and coarse atomization in ascending order by size as shown in Figure 2.8.

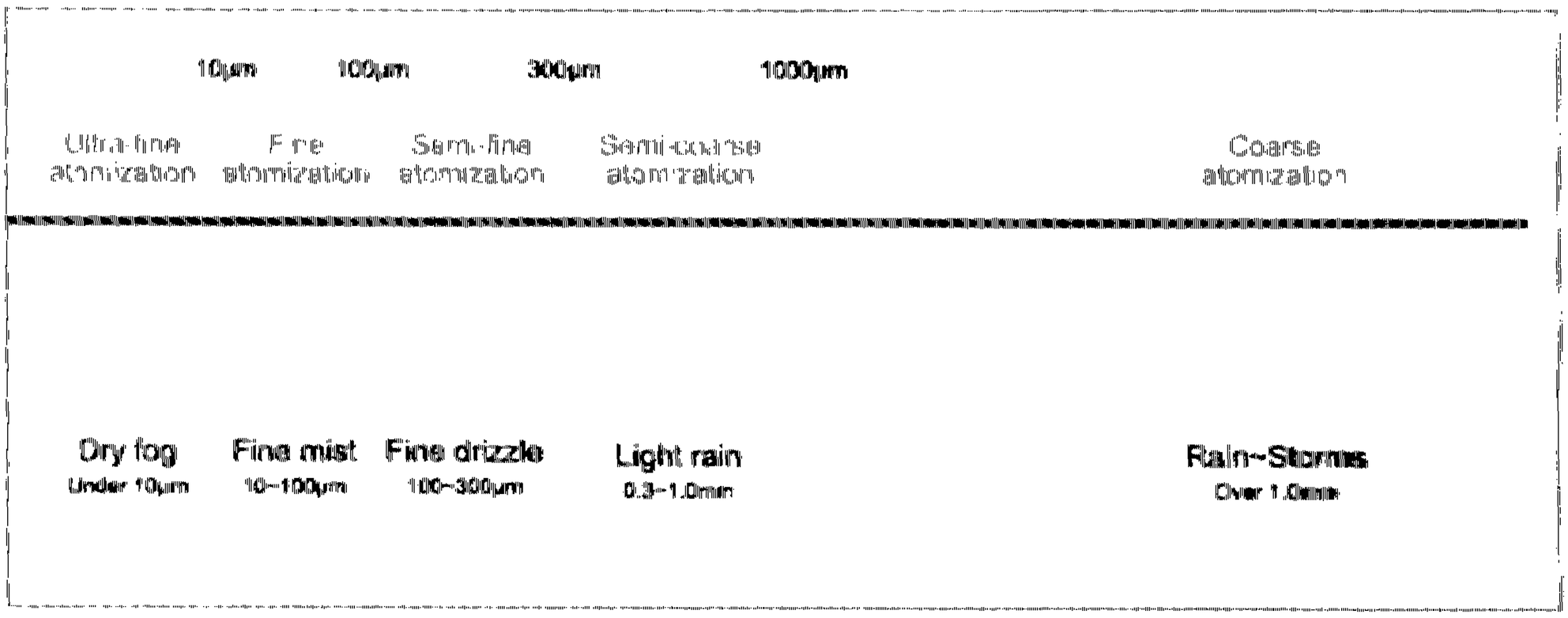

Figure 2.8: Droplet size classification (Ikeuchiusa, 2011).

Droplet size varies and come in distribution with penetration distance and radial distance within a given spray (provided that all other parameters are constant). There are various kind of diameters used to represent the droplets size within a given spray each of them has specific application the best suited for. Sauter Mean Diameter (SMD) and Volume Median Diameter (VDM) are common diameter used to describe droplet size of a spray (Lefebvre, 1989). SMD express droplet size in term of surface area produced by spray while VDM express droplet size in terms of volume of liquid sprayed. The equation of SMD and VDM are given as (Sauter, 1928):

$$SMD = D_{32} = \frac{\sum_{i=1}^{k} n_i D_i^3}{\sum_{i=1}^{k} n_i D_i^2} \tag{2.1}$$

$$VMD = DV0.5 = \frac{\sum_{i=1}^{k} n_i D_i^4}{\sum_{i=1}^{k} n_i D_i^3} \tag{2.2}$$

where n is the number of droplets within a range of is centered on diameter D_i, and k is the number of ranges. Other mean diameters used to describe spray droplet size are Arithmetic Mean Diameter (D_{10}), Surface Mean Diameter (D_{20}), and Volume Mean Diameter (D_{30}). D_{10} is best used when calculation of evaporation rate is required while D_{20} is best suited for application of surface controlling, such as absorption. As for the D_{30}

it is usually used for volume controlling application like hydrology. There are several factors affecting droplet size and one of them is the nozzle type. Generally, hollow cone nozzle forms smallest droplet size followed by flat nozzle and full cone nozzle. Other factors like flow rate has direct relationship to droplet size while spraying pressure and spray angle have inverse relationship to droplet size. Apart from those parameters, liquid physical properties also affect droplet size especially viscosity and surface tension. Both of them have direct relationship to droplet size.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

The project commences with background study of spray characterization and the coating liquid which is liquid modified starch. At this point, vital information to achieve project's objectives is acquired. Parameters required to completely characterize a spray are known. In addition to that, the factors influencing a given spray's droplet size, spray velocity profile as well as spray droplet breakup structure are identified. Mechanical and chemical properties of liquid modified starch are studied and compared with those of water.

Then, familiarization of LDA/PDA equipment and related procedures took into place. Steps to ready the instruments to acquiring data from the software operating the whole instruments were practiced. Besides that, experiment done by previous FYP student is observed. From this observation, recommendation was made to improve the experiment of the spray. For instance, instead of manually adjusting spray to have spray droplets passing through the LDA/PDA lasers intersection point, transverse system of LDA/PDA was utilized to move the lasers intersection point. By doing so, flow direction of spray was not interrupted making it more consistent when experiment was done at various pressures.

The next step was to prepare the liquids to be tested and they are liquid modified starch and water. Apart from that suitable nozzle types and specifications to be used for the project was determined as well as suitable pump for those nozzles. After that was the process of acquiring quotations and making purchase for the nozzles and pump. Next, all necessary tools & equipments were obtained and installed. The experiment of the spray was conducted on both of the liquids. Three values of pressures were chosen to vary the results with fluid's pressure. Lastly was the result analysis to determine all the investigated spray parameters and their relationship with their influencing factors. Figure 3.1 shows the process flow of the whole project.

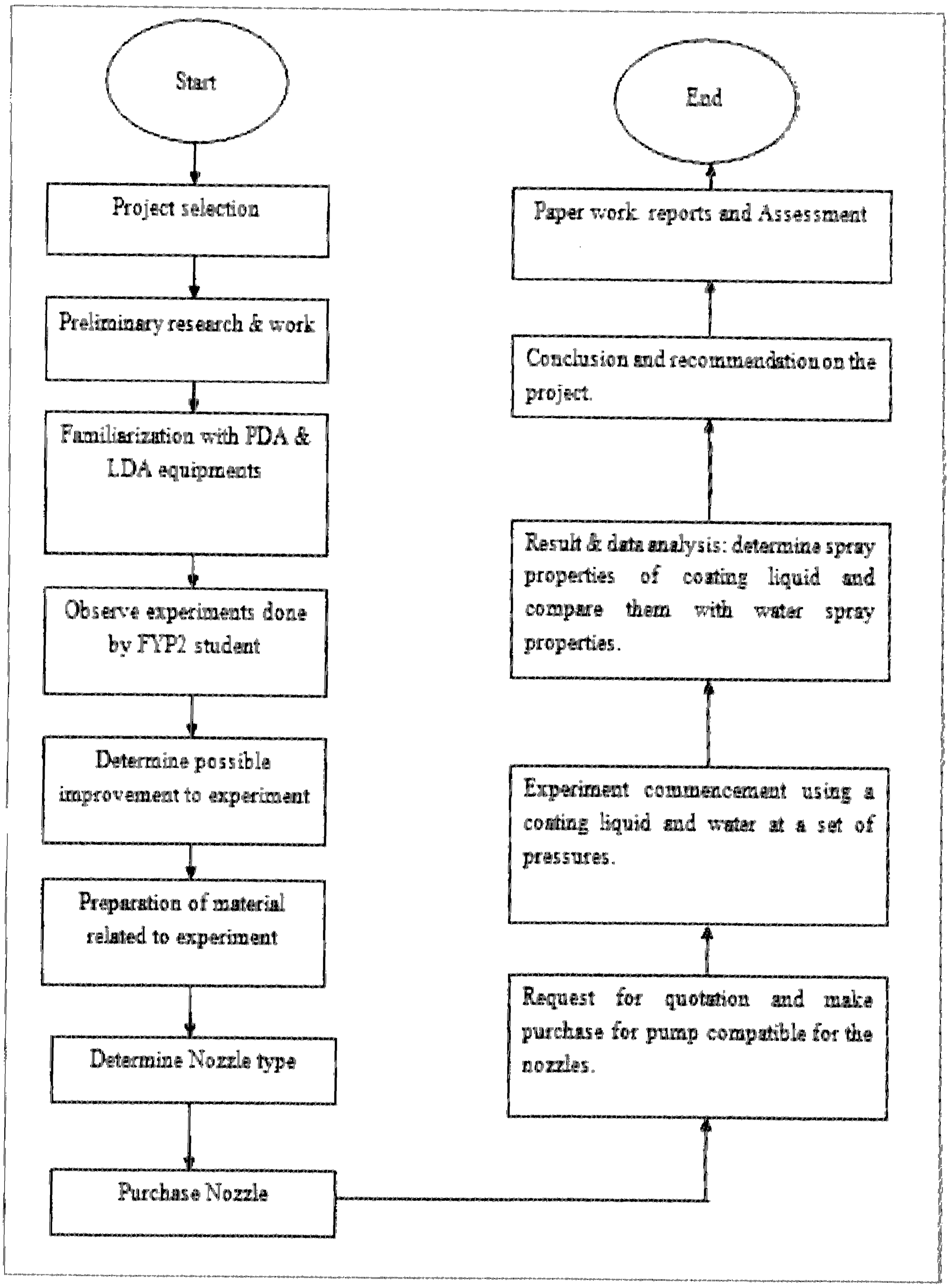

Figure 3.1: Process flow of the project

3.2 Project Activities

Gantt chart of the project was planned as below:

No.	Detail / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project selection														
2	Preliminary research and work														
3	Submission of proposal														
4	Proposal defense														
5	Project work familiarization on PDA & LDA Observe experimentation of FYP2 student on the similar topic Determine possible improvement for experiment														
6	Commencements of experimental work using LDA/PDA														
7	Data analysis Comparing data with experiment on different material														
8	Submission of Interim Draft Report														
9	Interim report														

Figure 3.2: Timeline-FYP1

No.	Detail / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Experiment using LDA/PDA Improve on experiment, get data with more sampling rate															
2	Utilization of high spped camera to determine spray angle and droplet breakup structure.															
3	Submission of progress report															
4	Data Analysis Ensure result to achieve project objective															
5	Pre-EDEX															
8	Submission of draft report															
9	Submission of dissertation & technical paper															
10	Oral presentation															
11	Submission of final dissertation															

Figure 3.3: Timeline-FYP2

3.3 LDA/PDA

LDA/PDA manufactured by Dantec Dynamics was used for this project. This equipment is located in Block N of Universiti Teknologi Petronas. Here are the specifications of the equipment:

Dantec Dynamics (manufacturer)

- A 300mW argon-ion laser source, Laser Physics Reliant 500m;
- A laser splitter and manipulator, Dantec 60 × 26;
- A signal processor, Dantec 58N80-MultiPDA;
- Optical-fiber cables, to convey the beams to the transmitter;
- A transmitter with a convergent lens, $f = 600\ mm$;
- A receiver with a convergent lens, $f = 300\ mm$;
- A traverse system Dantec 57G15

3.3.1 Laser Doppler Anemometry (LDA)

LDA is a device used to measure spray droplet velocity profile (Dantec, 2011). This device use spatial sampling method where collection of drop in a given volume is sampled instantaneously. It is basically consist of three major components which are a transmitter, receiver and computer. This device measures the scattered light intensity caused droplets as they went through sampling area. A curve-fitting diagram is then used to convert the data into velocity profile. Spray droplet velocity is calculated from the Doppler frequency of the signal from any of the detectors. The equation used to calculate the spray velocity is as follows:

$$U = \frac{\lambda}{2\sin(\frac{\theta}{2})} f_D \qquad (3.1)$$

Where U is spray droplet velocity, f_D is the Doppler frequency, θ is angle of lasers intersection while λ is the wavelength. Figure 3.4 shows instruments used in LDA.

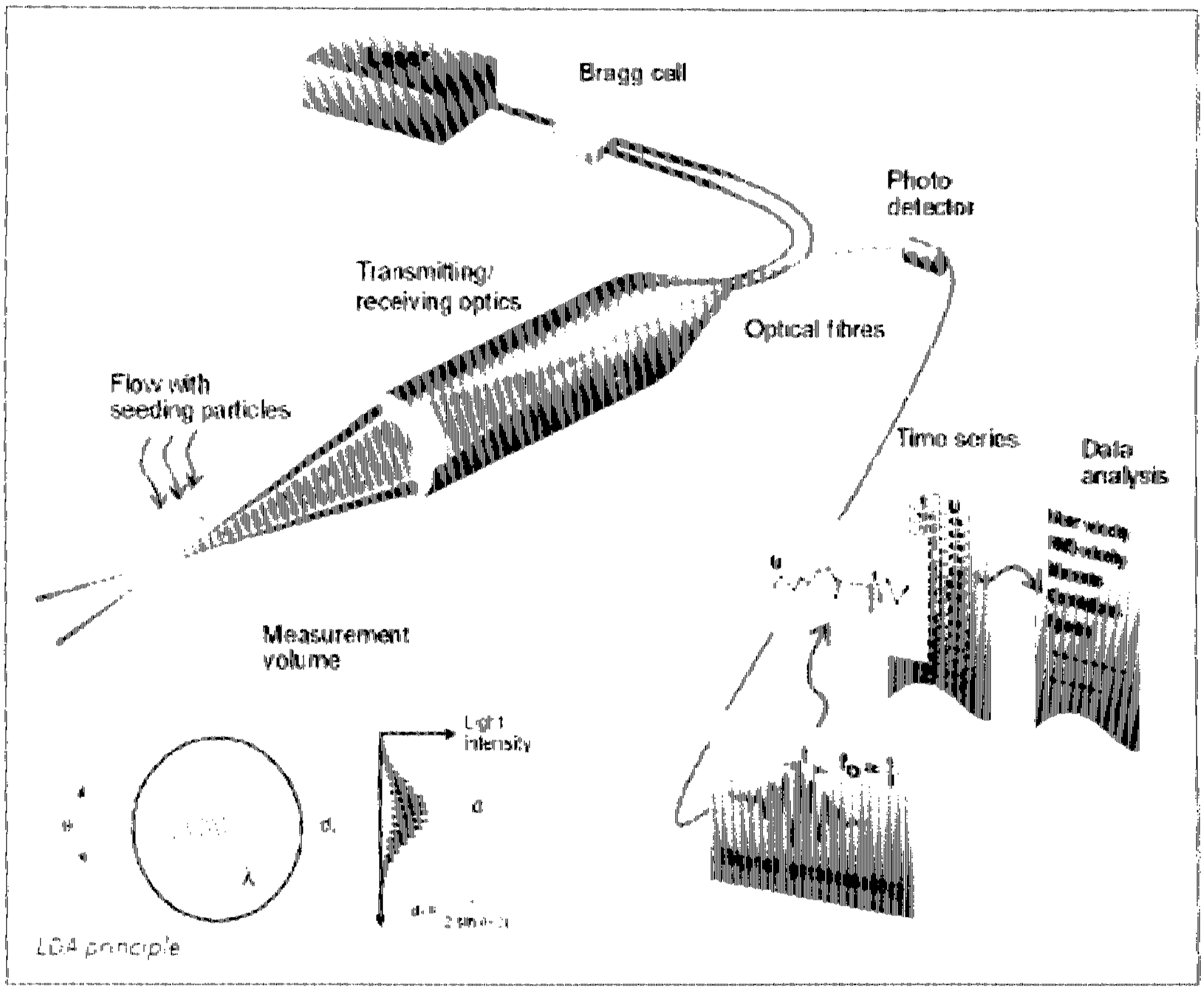

Figure 3.4: Laser Doppler Anemometry (Dantec, 2011).

3.3.2 Phase Doppler Analyzer (PDA)

PDA is a device capable of measuring droplet size (Dantec, 2011). It use flux sampling method in which individual drops pass through the cross section of a sampling region and are examined during an interval of time. This device is made of components like transmitter, receiver, signal processor and computer. Laser beams are used to form a point called probe volume. At this point, when droplets pass though it, scattered interference is formed and sweeps past receiver at Doppler difference frequency. This frequency processed to measure size of droplet. The droplet size is derived from the difference of phase between signals from two detectors. The equation for the spray droplet size is as follows:

$$\phi = \frac{2\pi D}{\lambda} \frac{\sin\theta \sin\Psi}{\sqrt{2(1-\cos\theta \cos\Psi \cos\varphi)}} \tag{3.2}$$

$$\phi = \frac{-2\pi D}{\lambda} \frac{n_{rel} \sin\theta \sin\Psi}{\sqrt{2(1+\cos\theta \cos\Psi \cos\varphi)(1+n_{rel}^2-n_{rel})}\sqrt{2(1+\cos\theta \cos\Psi \cos\varphi)(1+n_{rel}^2-n_{rel})}} \quad (3.3)$$

where D is droplet size, λ is the wavelength, θ is the angle of lasers intersection, φ angel between transmitting optics and receiving optics while Ψ is the angle between photo detectors. The former equation is used when light scattering dominated by reflection while the later is when light scattering dominated by refraction. Below is Figure 3.5 showing instruments used in PDA.

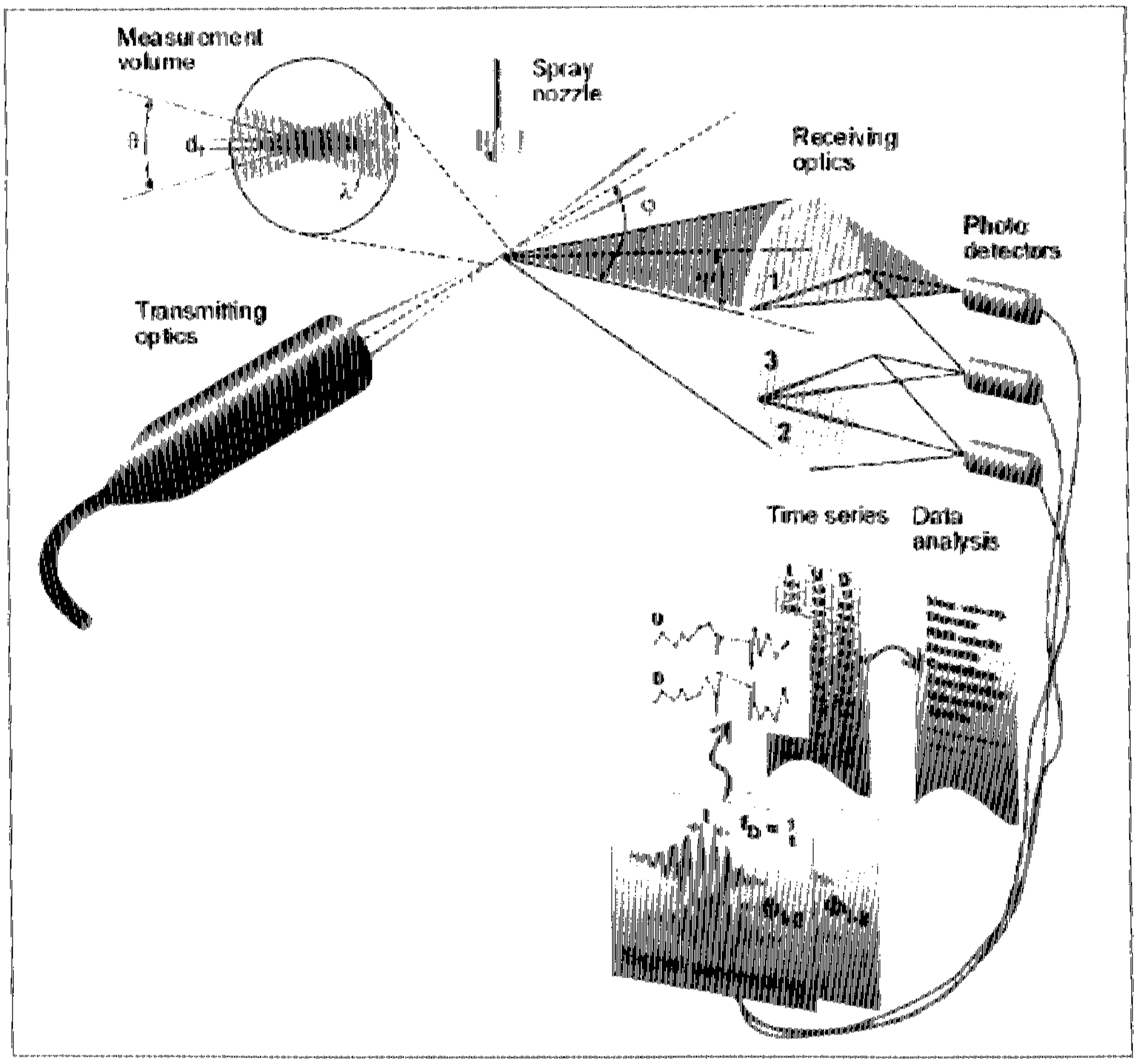

Figure 3.5: Phase Doppler Analyzer (Dantec, 2011)

3.4 High Speed Digital Camera

High speed digital camera will be used to capture image of the spray. It capable of recording thousands of high resolution images per second. The system consists of two major components which are the camera itself and Phantom Camera Control software. The software enables user to control setting to the image to be captured like shutter speed, resolution of the picture and light exposure. From the image captured, droplet breakup structure could be determined and the spray angle could be measured. By knowing the droplet breakup structure, level of atomization of the spray could be determined. On the image captured, two lines were drawn to mark the spreading of the spray. The angle between these lines is measured using protector. Here are the specifications of the equipment:

Phantom v9.1 (manufacturer)

- Full frame 4:3 aspect ratio CMOS sensor composed of 1,632 x 1,200 pixels;
- 14-bit image depth;
- 1,000 frames per second full resolution to 153,846 fps maximum;
- 2400 ISO/ASA monochrome, 600 ISO/ASA colour sensitivity equivalency;
- 24 Gigabytes DRAM, 24 Gigabytes non volatile flash memory;
- Extreme dynamic range exposure control.

Figure 3.6 below is an image of the high speed camera system.

Figure 3.6: High Speed Camera Phantom v9.1

3.5 Spray rig (pump & piping)

Spray rig was used to supply fluid to the nozzle. The system consists of a centrifugal pump, fluid tank, piping, valves and pressure gauge. The specifications of the pump are as follows:

- Single phase LEO pump;
- Maximum flow rate of 80 lit./min;
- Max head pressure is 64 meters;
- 1.5 horsepower;
- Inlet size of 1 ¼ inches, outlet size of an inch.

The Figure 3.7 below shows the schematic diagram of the spray rig used for this project.

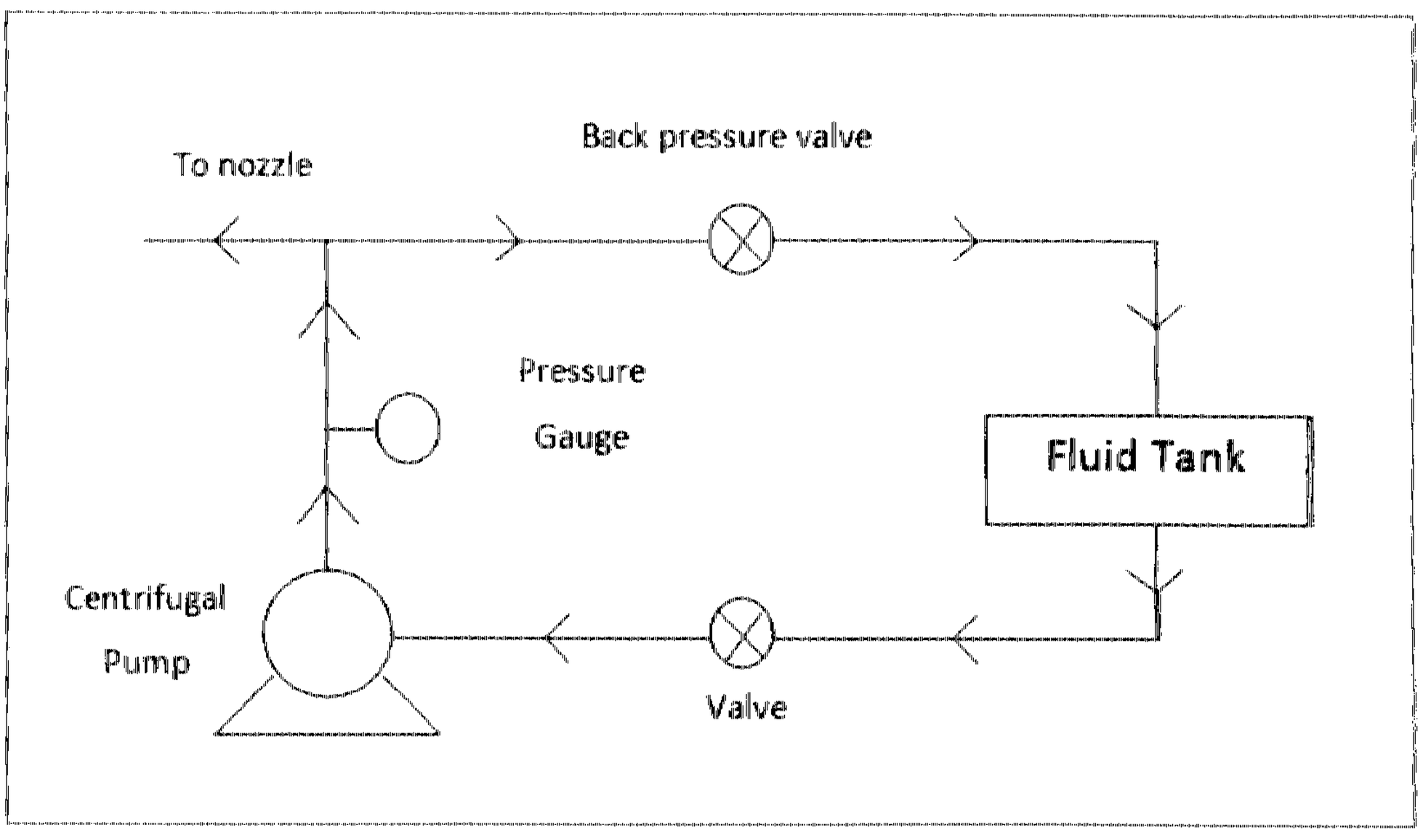

Figure 3.7: Schematic diagram of the spray rig used.

3.6 Spray nozzle

The spray nozzle used throughout the project was the high pressure nozzle F-75s manufactured by Akoka. The following is the specification of the nozzle.

- Full cone nozzle type;
- Nozzle outlet diameter of 1.3 mm;
- Air inlet of 6.35 mm.

3.7 Spray penetration

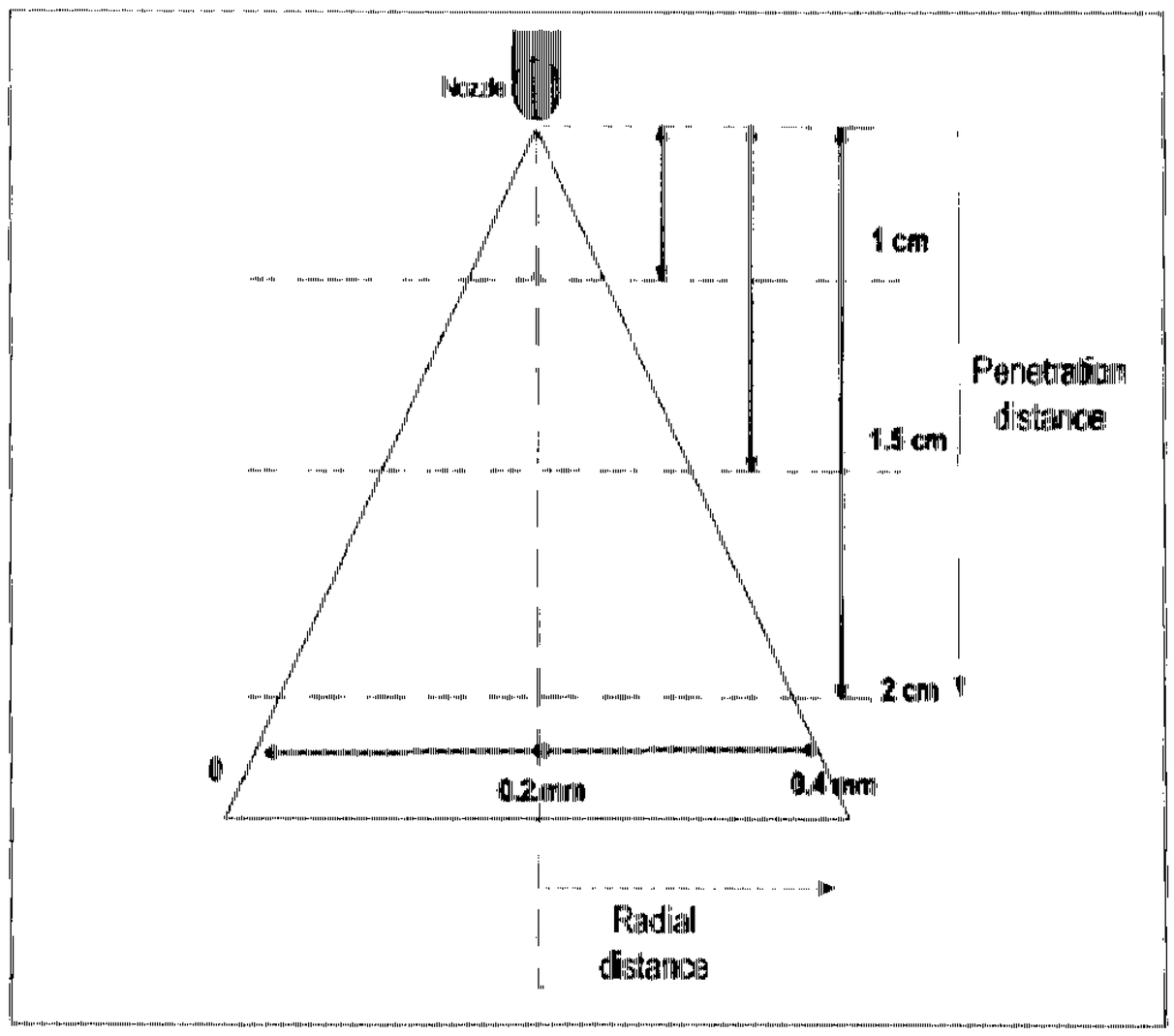

Figure 3.8: Spray distance from nozzle tip (Annaorazov, 2010).

Figure 3.8 above shows the penetration distance and radial distance covered in a given spray. Throughout the experiment, data of spray droplet size and velocity is taken from various penetration distance and radial distance from the nozzle tip.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Physical properties & sample data

The Table 4.1 below shows the physical properties comparison between liquid modified starch and water. The properties such as viscosity and surface tension will influence the spray's breakup structure, droplet size and droplet velocity profile of both liquids.

Table 4.1: Physical properties comparison (Ackland, 2007)

Properties	Starch	Water
Chemical formula	$(C_6H_{10}O_5)_n$	H_2O
Molecular weight	162	18.015
Density, kg/m3 at 20°C	1.6	0.9982
Viscosity, cP	50	0.890
Surface tension, mN/m	56	72.75

Figure 4.1 below shows a sample of raw data obtained from LDA/PDA. LDA1 is the horizontal velocity of spray, LDA4 is the vertical velocity of droplets and D is diameter of spray droplets.

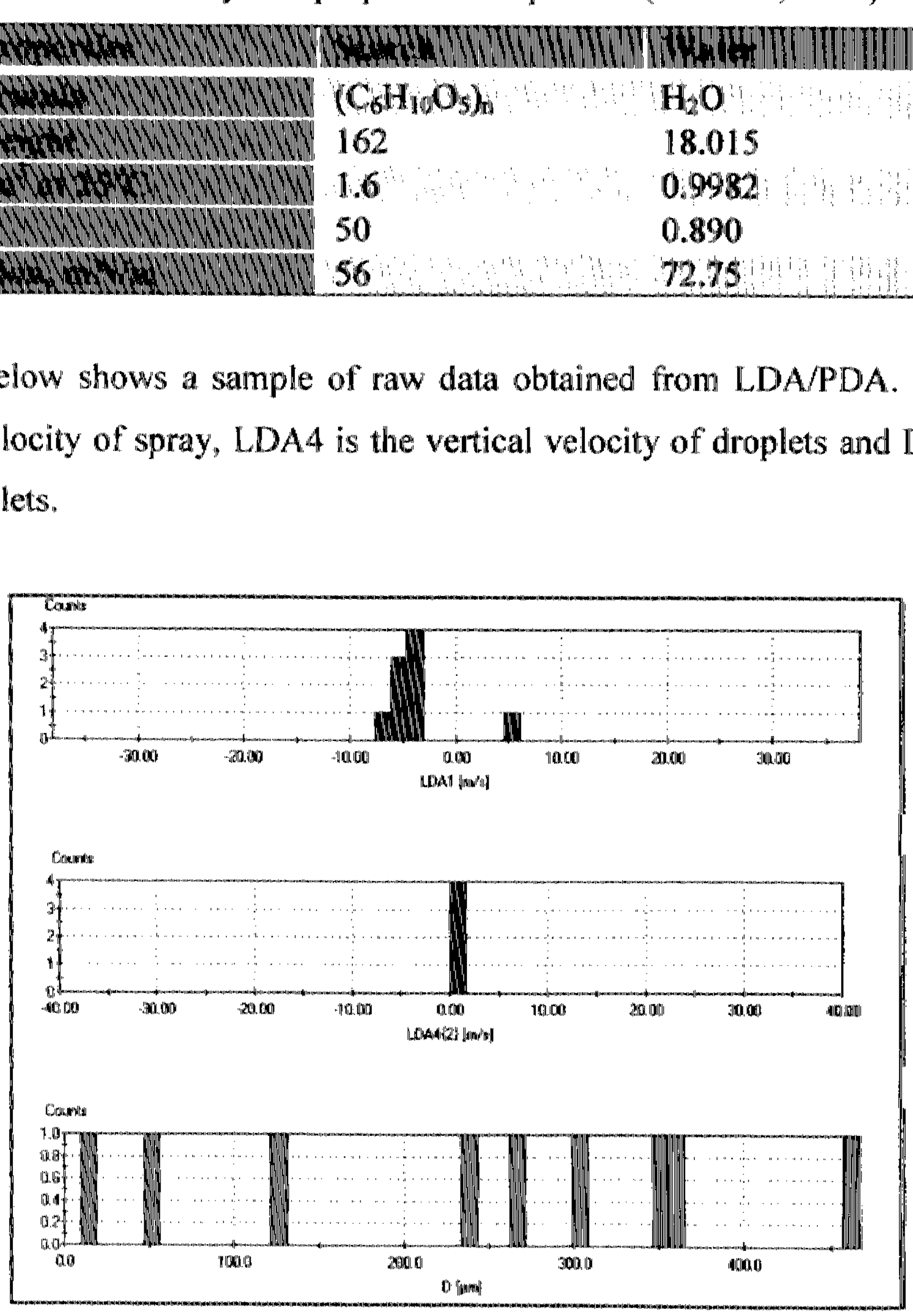

Figure 4.1: LDA/PDA data sample.

4.2 Sauter Mean Diameter

Spray droplet size of both liquid modified and water was compared. Figure 4.1 shows the results of the both liquids.

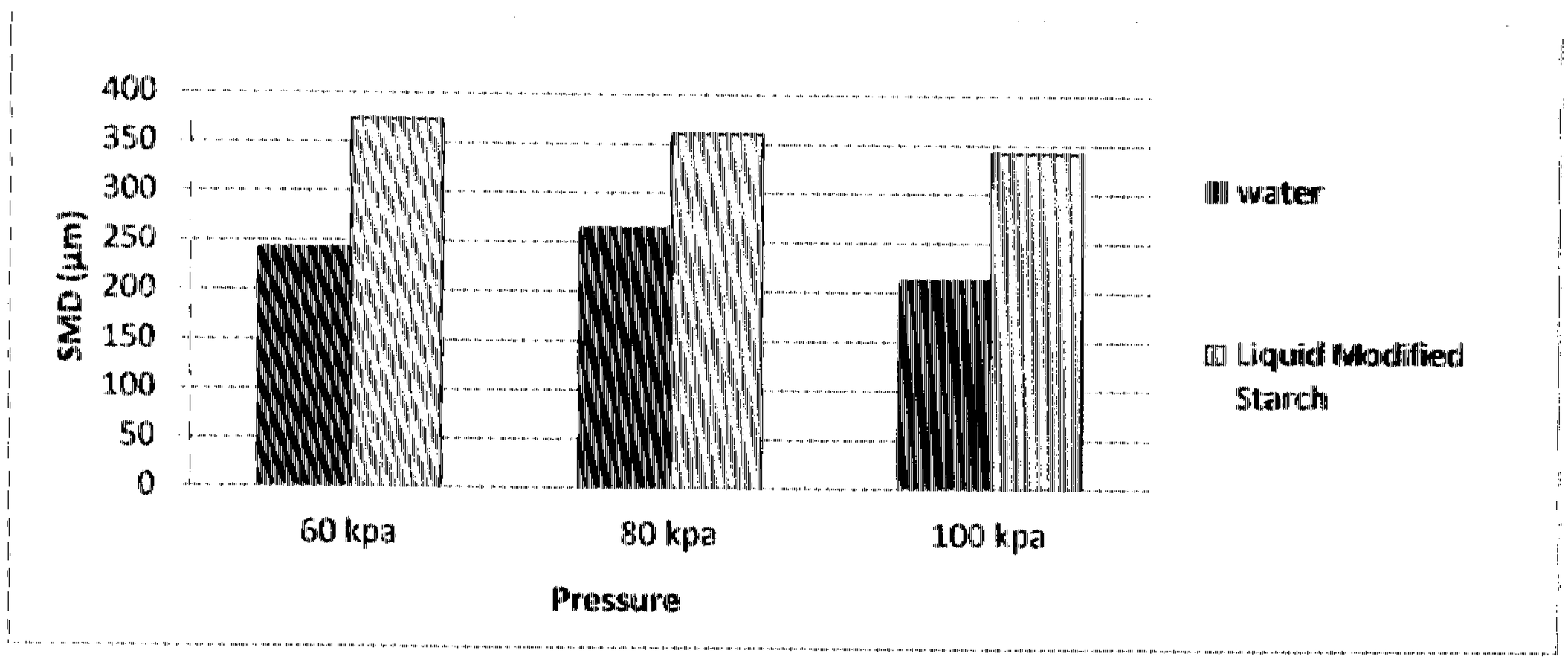

Figure 4.2: Sauter Mean Diameter at 1.5 cm vertical distance from nozzle tip.

As mentioned previously in the Chapter 2, the spray droplet size was measured using Equation (2.1) and the data obtained via LDA/PDA. The sample of the calculations could be found in the appendices. Spray droplet size was measured at three different pressures of 60 kPA, 80 kPA and 100 kPA. Based on the figure, it is known that spray droplet size of the liquid modified starch decreases as the pressure increases. Water however, shows slight increase in droplet size from 60 kPA to 80 kPa and then decrease afterwards. At any particular pressure, liquid modified starch has bigger droplet size compared to water. Liquid modified starch has the biggest droplet size of 374 µm at 60 kPa while water has the largest droplet size of roughly 265 at the pressure of 80 kPa. Liquid modified starch droplet sizes at all of the pressures are categorized as semi-coarse atomization while water droplet sizes falls into semi-fine atomization. The droplet size classification of the particle coating liquid is far from the achieved target of 30 – 60 µm which falls under fine atomization. It was estimated that the fine atomization could be achieved at pressure greater than 1500 kPa.

4.3 Spray vertical velocity

Spray vertical velocity is the velocity parallel to the spray flow direction which was downwards. Vertical velocity of given spray was measured by averaging all droplets velocity in that particular spray data obtained through LDA/PDA. Below is Figure 4.2 showing results regarding vertical velocity at vertical distance of 1.5 cm and 0 cm horizontal distance from nozzle tip.

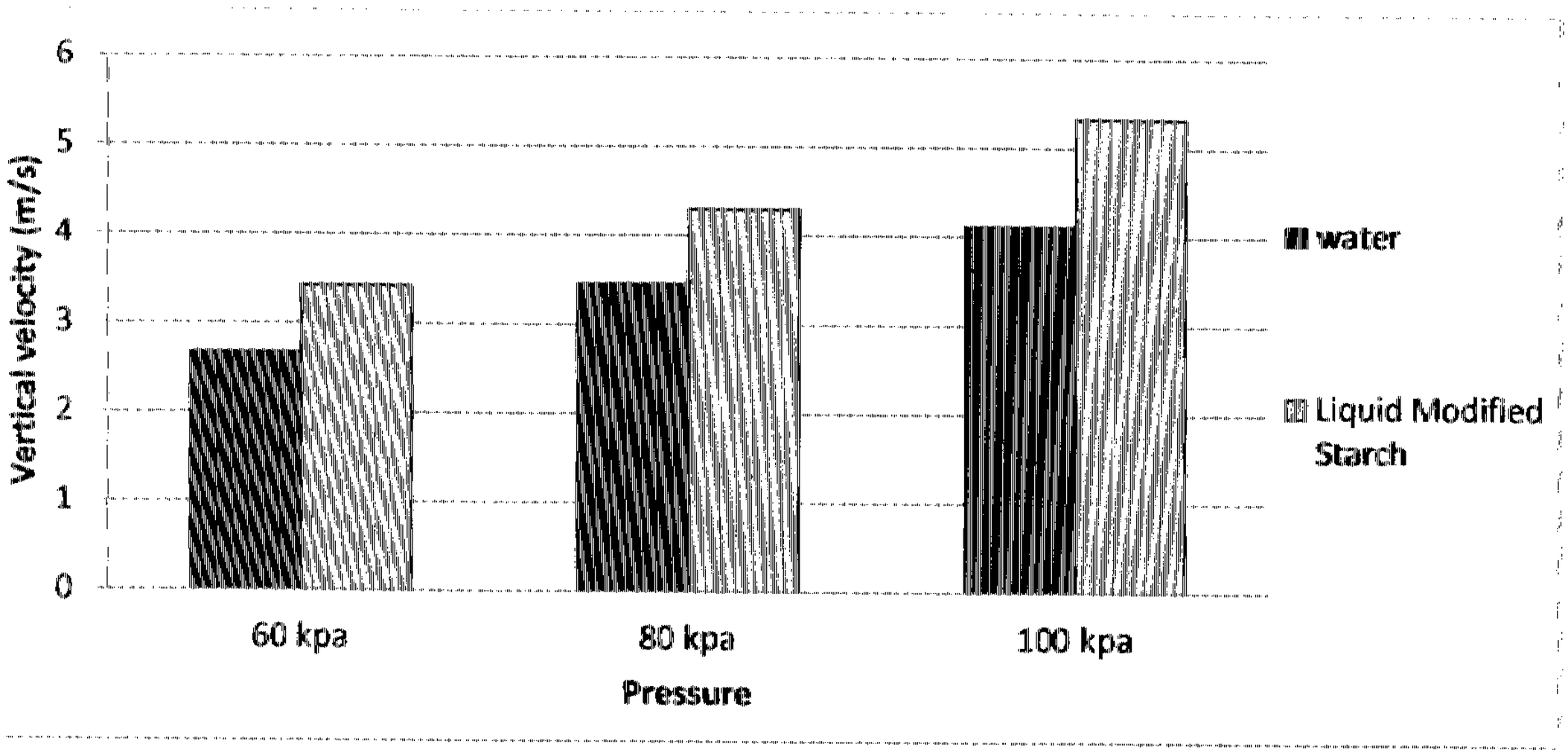

Figure 4.3: Vertical velocity of spray droplet.

From the Figure 4.2 above, both of the liquids show the trend of increase in velocity as the pressure on the fluids increase. At every pressure where data is taken, liquid modified starch has higher magnitude in vertical velocity than water. This implies that liquid modified starch spray could reach greater penetration distance at any pressure as compared to water.

4.4 Spray horizontal velocity

Spray horizontal velocity is the velocity perpendicular to the spray flow direction which was downwards. Vertical velocity of given spray was measured by averaging all droplets velocity in that particular spray data obtained through LDA/PDA. Below is Figure 4.3 showing results regarding horizontal velocity at vertical distance of 1.5 cm and 0 cm horizontal distance from nozzle tip.

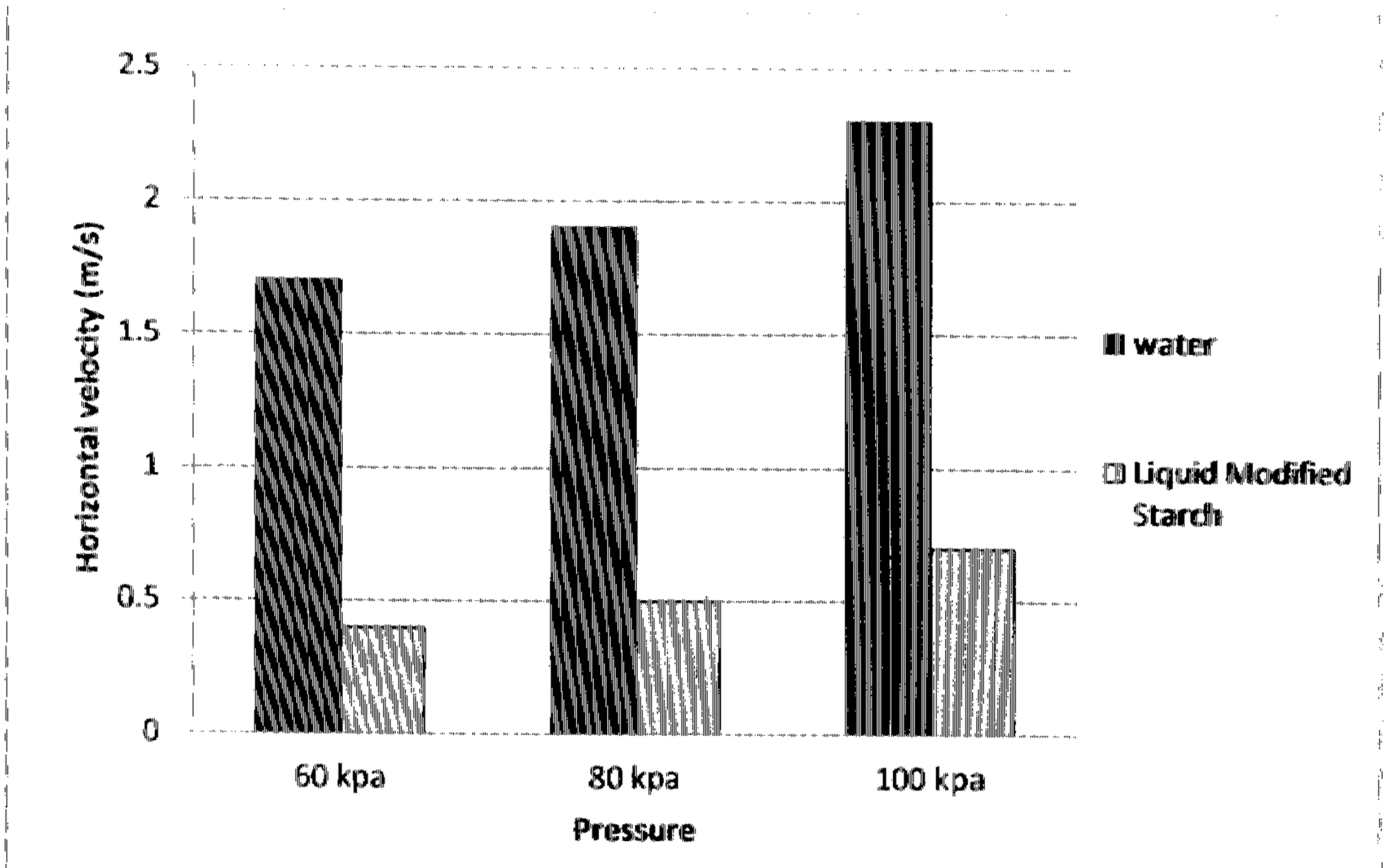

Figure 4.4: Horizontal velocity of spray droplet.

From the figure, both of the liquids show the trend of increase in velocity as the pressure on the fluids increase. At every pressure where data is taken, liquid modified starch has lower magnitude in horizontal velocity than water. This implies that water could reach greater radial distance at any pressure compared to liquid modified starch spray. Liquid modified starch has greater molecular weight than water. Thus, mass and inertia a droplet of the liquid is greater than water. When droplet's inertia is greater, the less affected it will be by turbulence flow of the spray which makes more droplet travels horizontally at higher velocity magnitude.

4. 5 Spray angles

To measure spray angles, pictures taken from high speed camera recording images of spray are used. High exposure and high resolution setting was used to get contrast of spray from background. Both of the liquids was sprayed the pressure of at 60, 80 and 100 kPA and images was taken via high speed cam. Software Catia V5R17 was utilized to measure the spray angles. Two straight lines are drawn along the spray width. The lines were extended until both of them intersect at one point. Using 2D measurement

option, angle between those lines were measured. Figure 4.4 below shows the example on the measurement of angle.

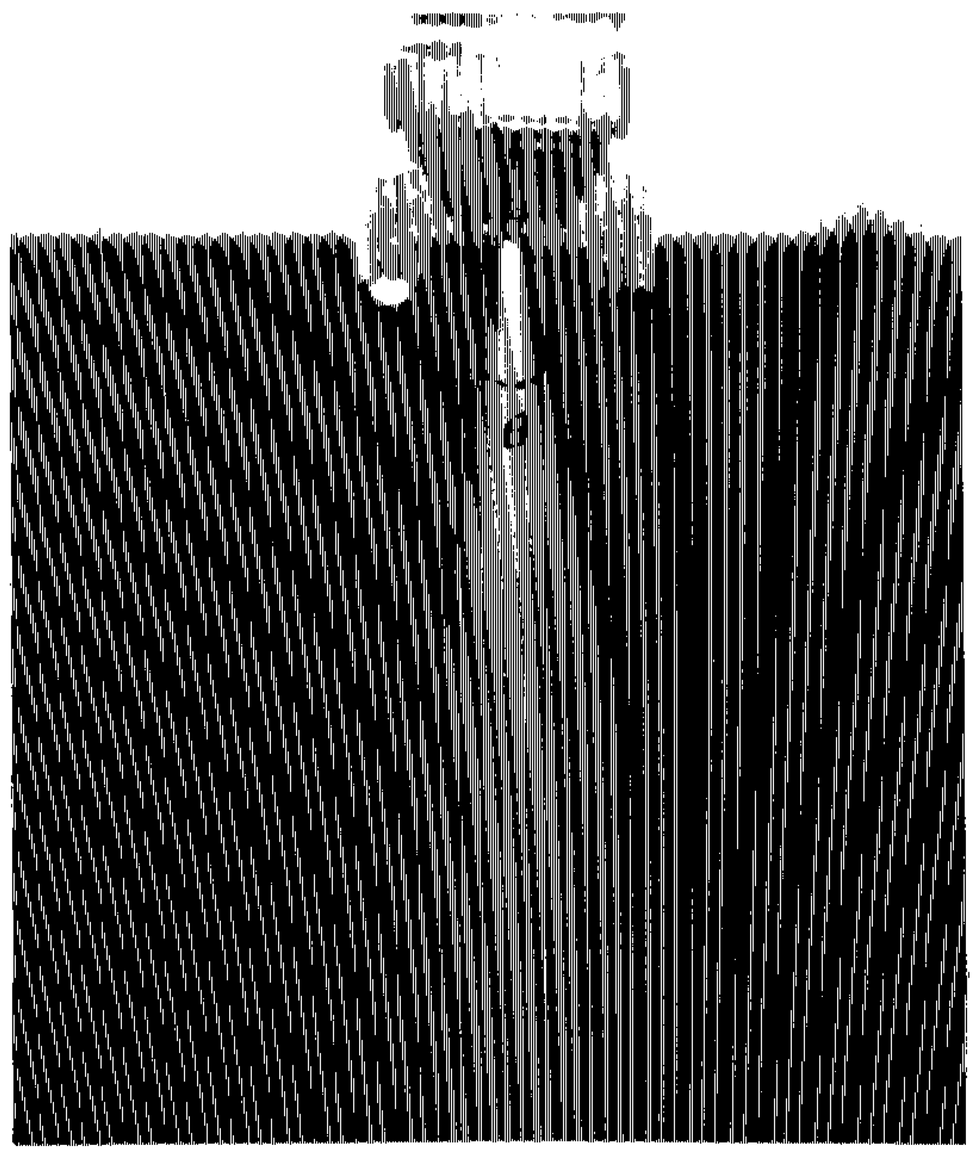

Figure 4.5: Spray angle measurement

4.5.1 Spray angles of water

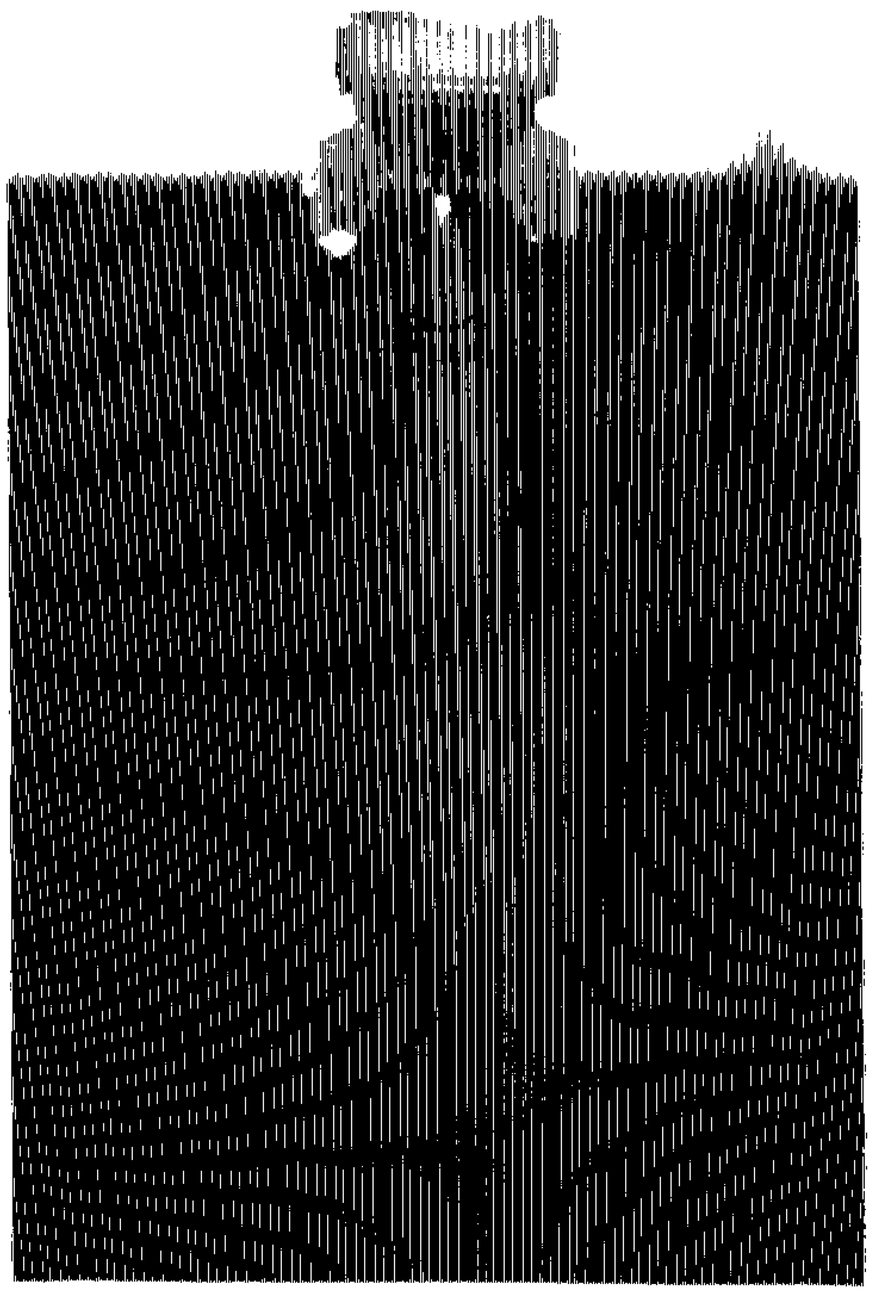

Figure 4.6: 19.5° spray angle of water at 60 kPa.

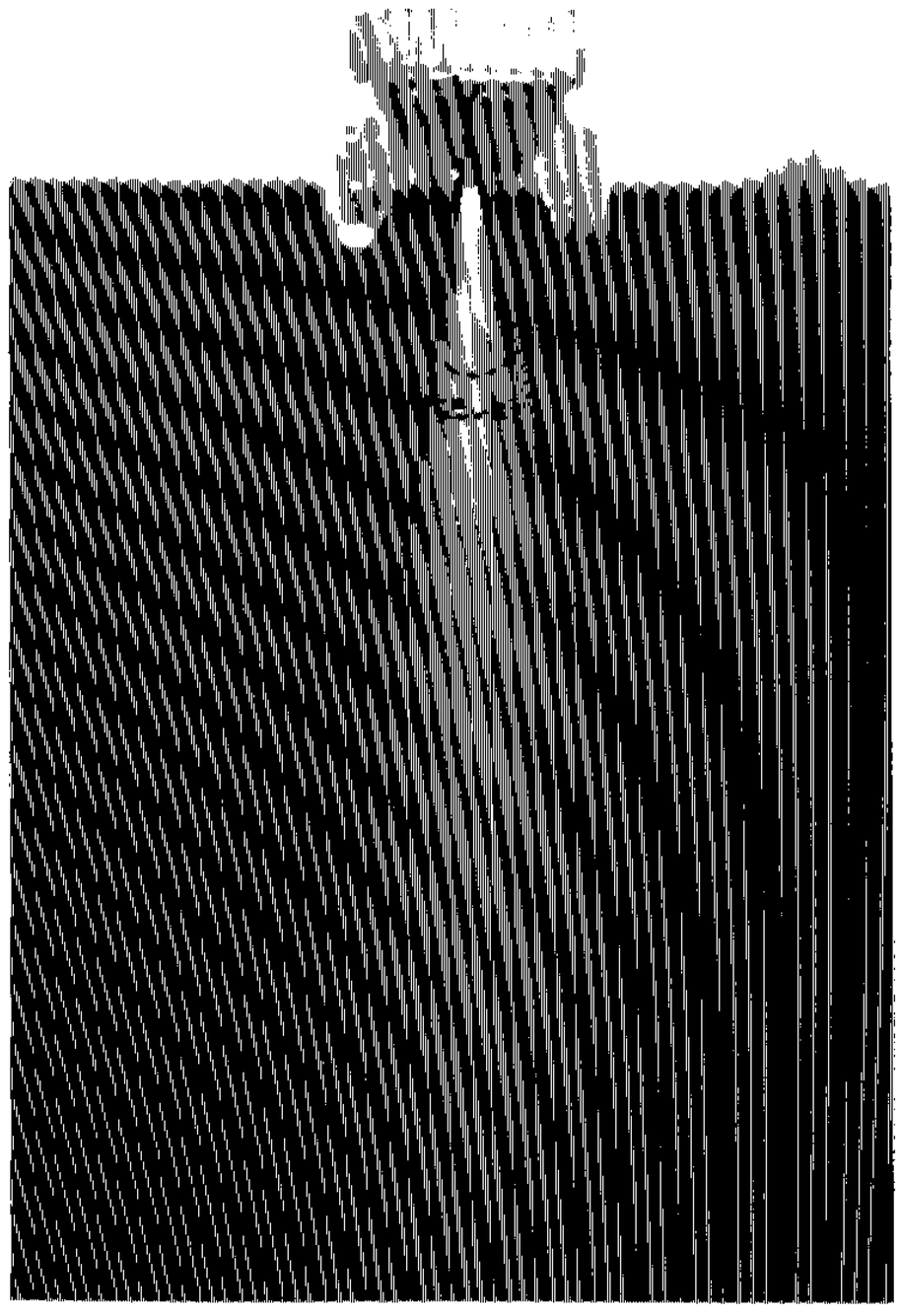

Figure 4.7: 25.46° spray angle of water at 80 kPa.

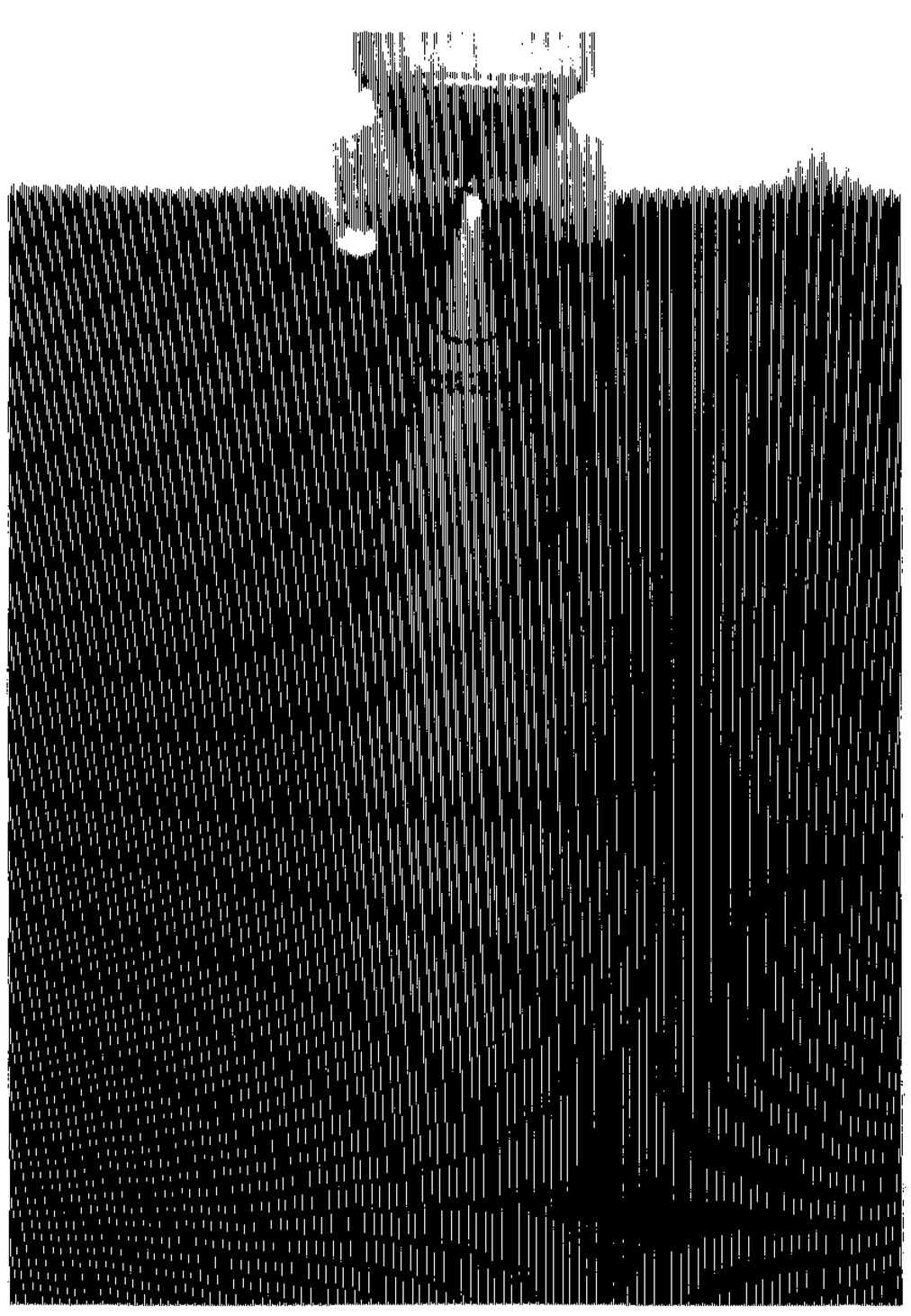

Figure 4.8: 28.284° spray angle of water at 100 kPa.

Water spray shows increase of spray angle as pressure increases. When the pressure increases, more droplets travel horizontally and at higher magnitude. As the result, spray width increases. Besides that, water spray also has larger amount of droplets produced when pressure increase. This is indicated by the increase in contrast of spray to the background of the images. Table 4.2 shows the results of water spray angle measurement.

Table 4.2: Spray angle measurement results of water.

[illegible]	[illegible]	[illegible]
Water	60	19.5
	80	25.46
	100	28.284

4.5.2 Spray angles of liquid modified starch

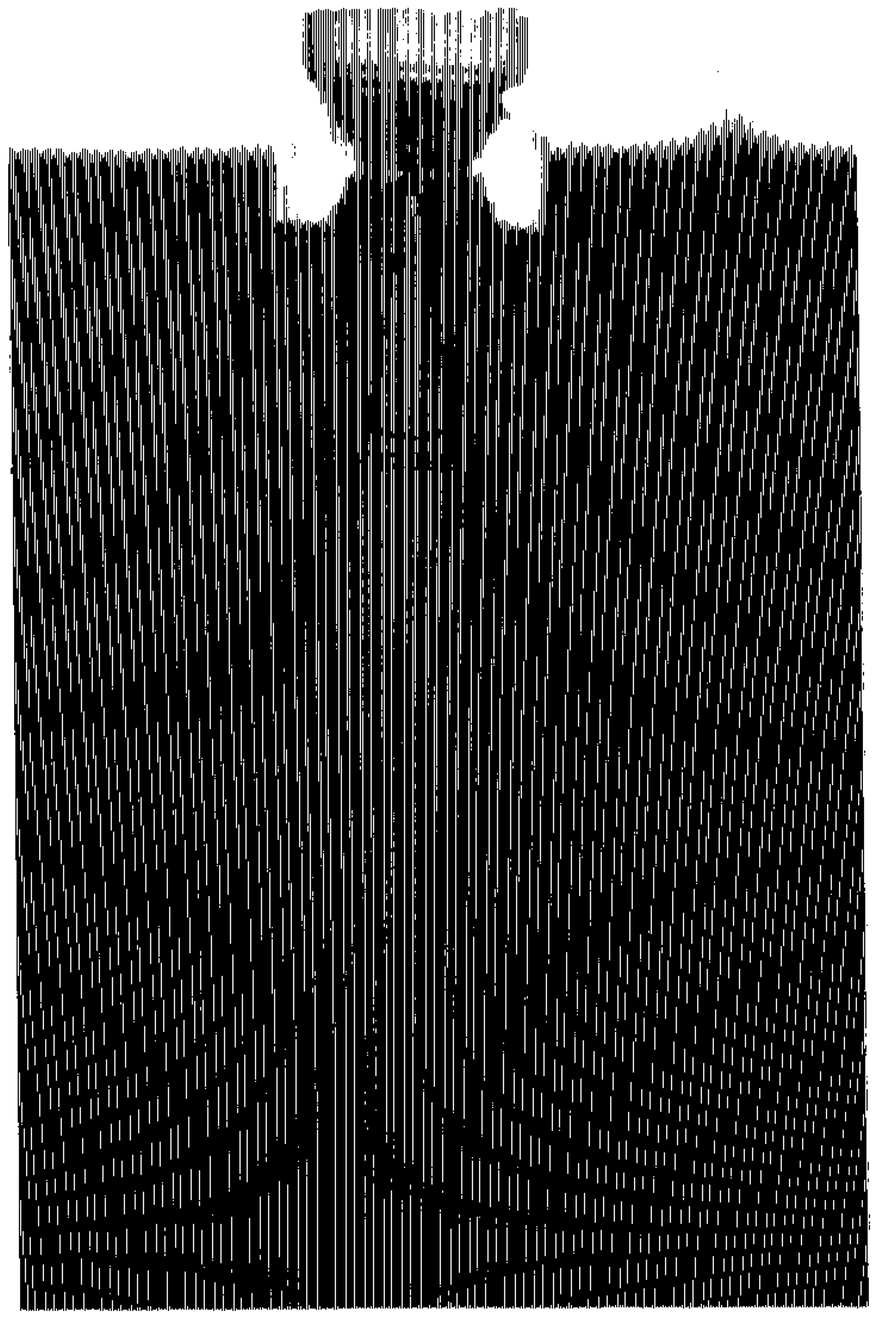

Figure 4.9: 17.151° spray angle of liquid modified starch at 60 kPa.

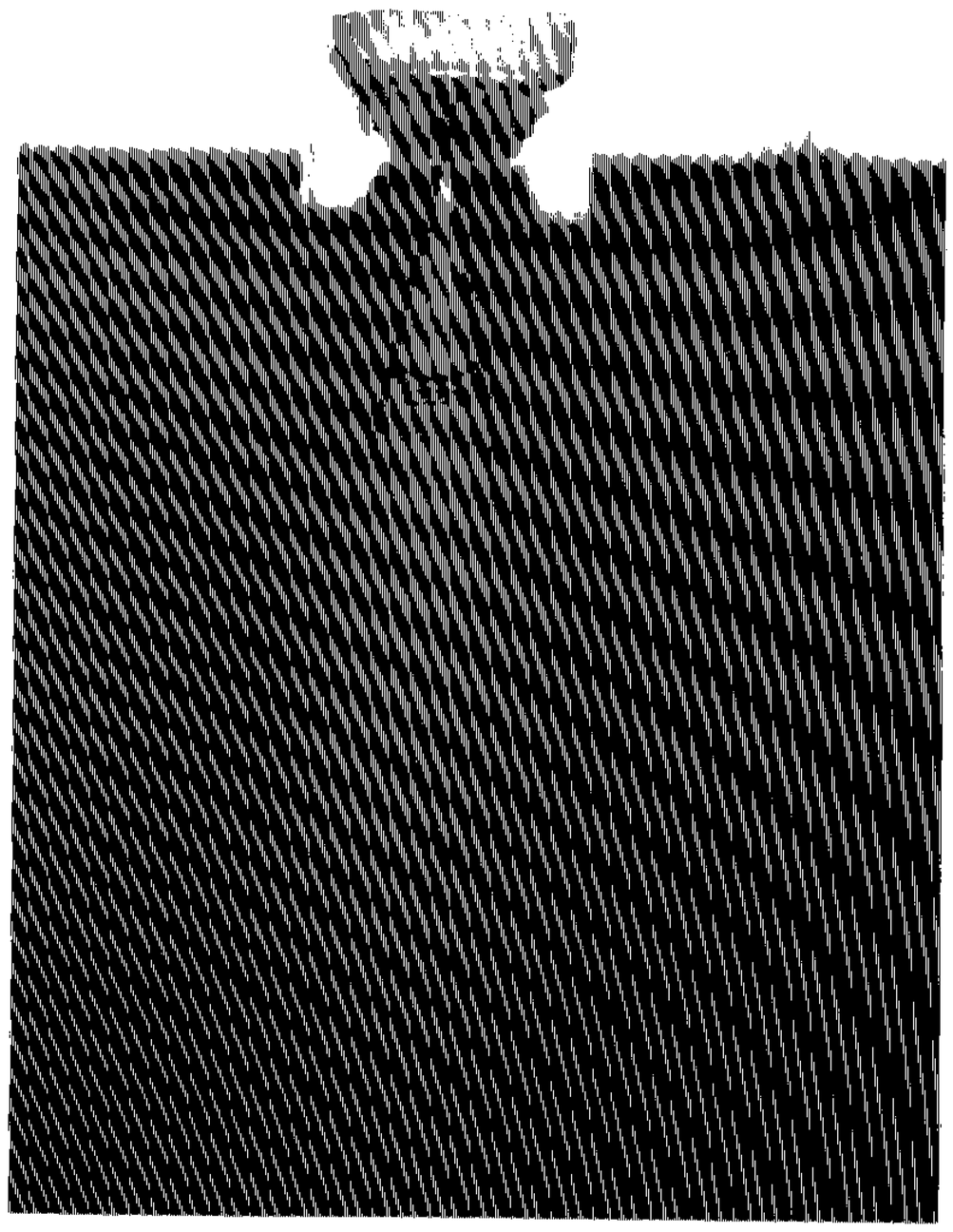

Figure 4.10: 22.279° spray angle of liquid modified starch at 80 kPa

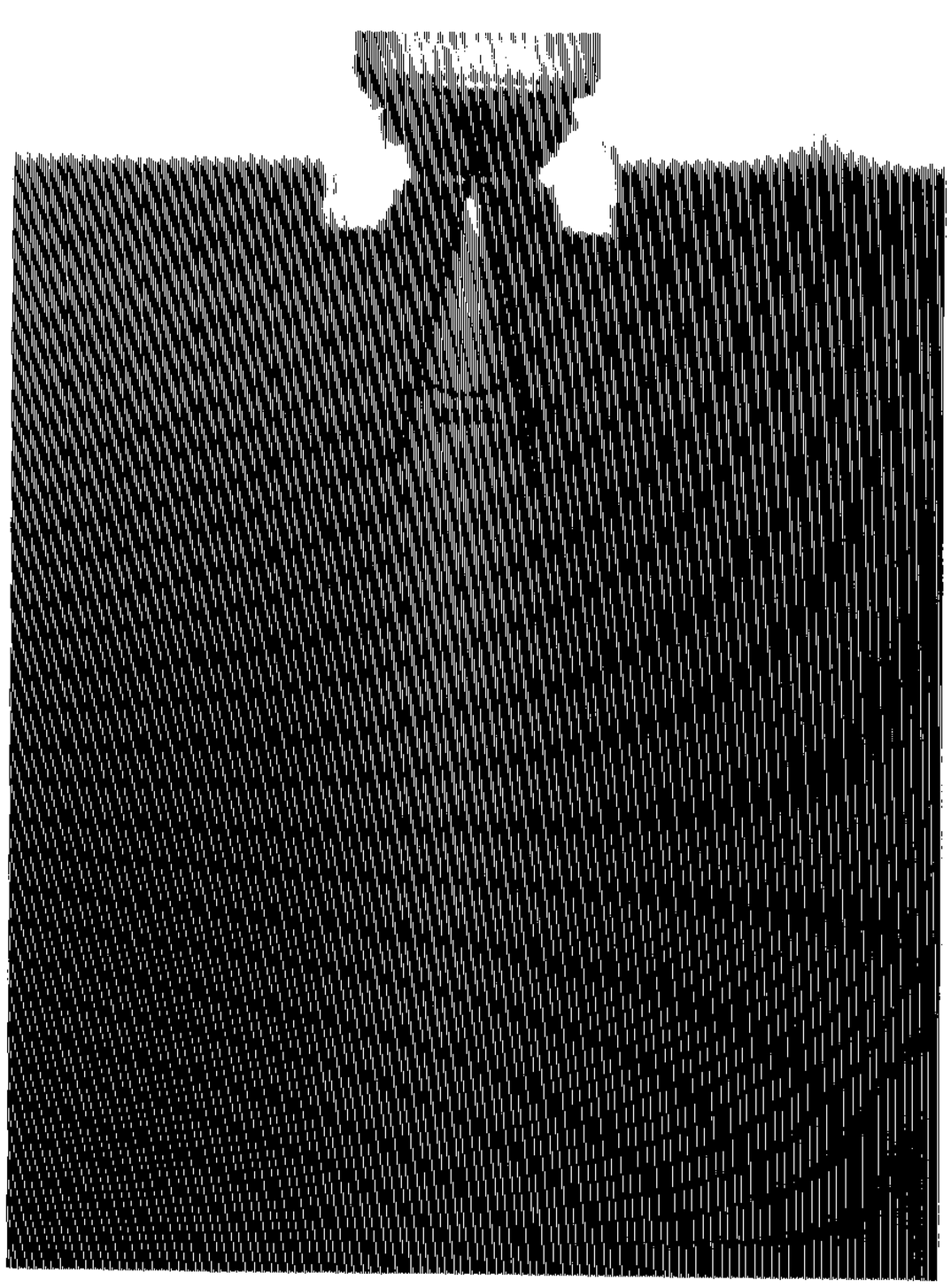

Figure 4.11: 25.304° Spray angle of liquid modified starch at 100 kPa.

Similar trend of water was also found on liquid modified starch spray where spray angle increases as pressure increases. When the pressure increases, more droplets travel horizontally and at higher magnitude. As the result, spray width increases. Apart from that, the spray also has larger amount of droplets when pressure increase. This is indicated by the increase in contrast of spray to the background of the images. Compared to the spray of water, the starch spray image has less contrast at any pressure. This shows that the amount of droplet in a given spray of water is greater than liquid modified starch at the same pressure. Spray angle results for liquid modified starch are shown in Table 4.3.

Table 4.3: Spray angle measurement results of liquid modified starch.

	60	17.151
	80	22.279
	100	25.304

From Table 4.2 and Table 4.3, it is known that water has bigger spray angle at any pressure compared to liquid modified starch. Both of the liquids shows increase in spray angle when pressure increases. However, the increment of spray angle for water is greater than spray angle of liquid modified starch. Mass per droplet of water is less than mass per droplet of liquid modified starch. So, water spray droplet has less inertia and its horizontal velocity is more easily affected by the pressure exerted.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The objective of this project is to characterize the basic properties of sprays and droplets of coating liquid for the fertilizer granules under different conditions. The basic properties that need to be determined are the breakup structure of spray droplet, spray droplet size, spray droplet velocity profile, spray angle, droplet concentration and spray penetration. These properties were determined by using LDA/PDA system and high speed camera system. From the LDA/PDA system, data such as spray droplet size and spray droplet velocity in both horizontal and vertical directions are obtained. While the high speed camera system enables spray angle to be determined. The experiments using the two equipments were done at three magnitudes of pressure and they are 60, 80 and 100 kPa.

Spray droplet size of liquid modified starch and water were determined by calculating the Sauter Mean Diameter using the diameters obtained from LDA/PDA. From the calculated SMD, liquid modified starch has greater spray droplet size than water at any pressure. This indicates that spray droplet size has the relationship of inversely proportional to the viscosity of the fluid. Besides that, it also can be concluded that droplet size of a given spray will increase if the pressure exerted on the liquids increases meaning that SMD is directly proportional to the pressure. For the application of coating fertilizer granules however, the SMD of liquid modified starch did not reach the targeted SMD of 30-60 μm. In order to achieve this droplet size range, it is estimated that pressure of greater than 1500 kPa should be exerted on the fluid.

As for the velocity profile of the spray, average velocity of droplets in the directions of vertical and horizontal were measured. It is found that both vertical and horizontal velocities are directly proportional to the pressure of the fluid. At any point of pressure, liquid modified starch has higher magnitude in vertical velocity compared to water. However, it is different for horizontal velocity as water has higher magnitude than liquid modified starch.

The spray angles for both liquids were also determined. Water has greater spray width at any pressure compared to liquid modified starch. For the application of coating fertilizer granules, bigger spray angle should be achieved to coat hundreds of granules simultaneously. In order to do so, higher pressure of fluid and hollow cone nozzle should be used in designing the fluidized bed coating system.

5.2 Recommendations

As recommendation, current spraying system available on the LDA/PDA lab should be upgraded or improved. This is important in order to produce better spray to get better reading on LDA/PDA system. In order to do so, higher quality nozzle should be used and suitable pump for the nozzle specification should also be taken into consideration. Besides that, the clamp used to hold spray nozzle should also be replaced with one more stable and could be accurately positioned to get the lasers intersect on desired spray's penetration distance and radial distance. The current clamp used highly inaccurate as its adjusting joints moves rotationally. Making it difficult to control placement of nozzle with respect to the point where the lasers from LDA/PDA system intersect.

Other than that, a dark room should be made for the purpose of using high speed camera. In a dark room better image of spray taken by high speed camera could be improve as higher contrast is achievable in the dark.

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APPENDICES

APPENDIX A

Calculation of SMD and velocity of a given spray

Table A-1: Sample data from LDA/PDA system.

40	3	-2.4
100	8	0.4
70	6	1.2

Sauter Mean Diameter, $SMD = D_{32} = \frac{\sum_{i=1}^{k} n_i D_i^3}{\sum_{i=1}^{k} n_i D_i^2}$

$$= \frac{(5)(40^3) + (12)(100^3) + (7)(70^3)}{(5)(40^2) + (12)(100^2) + (7)(70^{32})}$$

$$= 90.7024\ \mu m$$

Average vertical velocity, $\frac{\sum V}{n} = \frac{(5)(3)+(12)(8)+(7)(6)}{24}$

$$= 6.375\ \text{m/s}$$

Average horizontal velocity, $\frac{\sum V}{n} = \frac{(5)(-2.4)+(12)(0.4)+(7)(1.2)}{24}$

$$= 0.05\ \text{m/s (to the right)}$$